POLITECHNIKA LUBELSKA

# Aesthetics of road structures

*edited by*
*Sławomir Karaś*

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# Preface

Recent years have seen numerous monographs and papers on bridge aesthetics. Nevertheless, the very first two studies are still the most important. One of them is *O architekturze mostów* (*On the architecture of bridges*) (1971) a book by Zbigniew Wasiutyński, a professor at the Warsaw University of Technology, while the other – an album monograph by Fritz Leonhardt, a professor at the University of Stuttgart, *Brücken - Ästhetik und Gestaltung / Bridges – Aesthetics and Design* (1984).

Leonhardt's book has become the canon of bridge aesthetics studies. Well-thought-out sets of professional photographs are equipped with comments reflecting the method of finding elements and images in the whole structure in the context of aesthetic impressions. A static and monumental depiction of large bridges is prevalent which reflects the design at that time and results from the competition for the longest bridge span, the measure of material and technological progress in this discipline both then and now. Leonhardt designed bridges which where then actually constructed. As far as bridge mechanics is concerned, he significantly pushed the bridge construction limits, above all, in the case of cable-stayed and suspension bridges. It could be argued that in his time he was the leading constructor and authority in bridge mechanics and aesthetics.

The situation is different in the case of Wasiutyński's book, a much more in-depth and interesting work on bridge architecture, albeit difficult to read. Precisely that as even the abundance of bridge images in the book only serves as a clarification of the reflections on architecture and its objectives, psychophysics, emotions, impressions, the perception. Unfortunately, this valuable position is only accessible to the speakers of Polish.

The both monographs are slightly old-fashioned, if not historical, but at the same time the universal truths have not changed, let alone become devalued. Modern bridge construction only adds new chapters and examples of aesthetic bridges. This paper on the aesthetics of roads and bridges constitutes such an appendix. It is, at the same time, a discussion with the architectural milieu who appropriate the issue of the aesthetics of large-scale structures. At present, architects are not overly familiar with structural mechanics which contributes to the fact that the beauty of mechanics is often overlooked and a decorative detail or colours take its place instead. The situation is still worse in the case of the architecture of road as a linear engineering structure. Such reflections are actually non-existent. For that reason a book on the aesthetics of roads and bridges has been written by structural engineers.

It is said that the exception proves the rule and, indeed, an example of it can be Santiago Calatrava's bridge art which perfectly combines the structural analysis with the aim, i.e. foldability of frames. It is Calatrava that establishes the canons of bridge aesthetics. On the other hand, it is not necessary that every bridge should resemble the *Katehaki Footbridge.*

Another context for the aesthetics of roads and bridges is ecology or, to be more exact, the application of the concept of sustainable development.

Hundreds of kilometres of existing and constructed roads of transport infrastructure influence strongly the environment. We are still facing the unresolved dilemma between our strive for comfort and its negative side-effect, i.e. environmental degradation. So far, the only method of eliminating this antinomy has been its recognition and mitigation, e.g. the introduction of bridge passages for animals under or over roads or railways in order to limit the wildlife fragmentation. The effectiveness of such enterprises is measurable, although, on the other hand, rather low, despite high costs of ecological structures, sometimes up to 25% of the total investment costs.

In a very real sense there appears a new recipient of the bridge aesthetics and architecture – the environment. The measures of environment-friendly aesthetic impressions are concluded on the basis of the application of the human measures.

The authors of the book are the engineers from the Department of Roads and Bridges, Lublin University of Technology. The team was comprised of young, middle-aged as well as senior staff members, which gave an opportunity to consider the perspectives of at least two generations. The book is richly illustrated in recognition of the fact that an image can speak a thousand words.

# 1. Who watches the road structures

## 1.1. Introduction to aesthetics. Road structures *(SLK)*

'Aesthetics', first time used in the 18th century by Alexander Baumgarten[1], is derived from the Greek word for perception (αισθητική – aisthesis). Aesthetics, also esthetics *(US)*, refers to the nature of beauty and artistic taste.

The understanding of *aesthetics* and *aesthetic* consists of two similar categories:

- aesthetics could be a scientific discipline, a theory of beauty, emphasizing the evaluative criteria that are applied to beauty or art, for instance,
- aesthetic, commonly it means functioning of a measure of visual or other impression caused by a contact with somebody or something who/which generates mentioned felling; it is a study of the mind states and human emotions in relation to the beauty.

Let us recall some definitions of aesthetics:

- Aesthetics – the branch of philosophy that deals with the nature, expression, and perception of beauty, as in the fine arts. The study of the psychological responses to beauty and artistic experiences. [The Free Dictionary, by Farlex],
- Aesthetic – of, relating to, or dealing with aesthetics or the beautiful [Merriam-Webster, Encyclopaedia Britannica Company].

As shown, the difference between aesthetics and aesthetic is very slight and the Internet is full of options as well controversies in the discussed area.

For the sake of this paper, the following concept of aesthetics is assumed:

> *It is the feeling of a group of people that something is spectacular enough, harmonious, optimistically pleasant or synergic, something is worth mentioning, returning to, repeating or been treated as a pattern or as a symbol of deep sensation or excitation.*

Currently, the desire to own pictures of/with the an item that evoke an aesthetic experience may be a very useful, and in addition it may appear a statistical measure of a degree of aestheticism.

The above definition is very similar to the concept of the commonly known list of the *7 wonders of the world*. This idea has been present through millennia and for the reason it has a very strong practical basis. Historically, it is an old concept but it seems to be always valid.

On the other hand aesthetics could be linked with the perfection of mathematics. Mathematics is a pure science where the human intelligence, logics and deduction allow to discover the harmony and complexity of something which looks artificial but in reality is only discovering about the nature. If one ever studied even the most elementary proof of a mathematical theorem, they could feel some tension and enlightenment when they finally could read *which is what had to be proven*[2]. The aesthetic of mathematics is the glory of precise thinking.

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[1] Alexander Gottlieb Baumgarten (1714–1762), the creator of aesthetics as a science.

[2] The translation of Latin phrase quod erat demonstrandum, Q.E.D.

Somewhere *in the middle of the road* of aesthetics and aesthetic there are the aesthetical problems of road and bridges structures that constitute an important element of this part of civil engineering.

Civil engineering is the application of mathematics to classical physics, which is the foundation of such disciplines as soil mechanics, strength of materials, construction mechanics, the theory of elasticity and plasticity, construction materials and other disciplines. However, effects of civil engineers' actions also have a great social impact. These effects, in general, influence people, landscape and environment for many years, even generations. As a result, aesthetics is important because it shapes the mentality and behaviour of the present and future generations. At the same time it links the good tradition of construction to the challenges of the present.

In the case of aesthetics, road construction is easier to talk about than the aesthetic of bridges. Certainly, the basic rule is 'do no harm'.

The bridge may be more or less beautiful, but there is no detectable tendency of constructing visually unattractive bridges. The concept of ugliness is not, as yet, a prerequisite for bridge designers. Even if bridges turn out to be ugly, it is mostly the result of various unintended, short-term or transitional actions. Every bridge designer is aware that his/her work will function for about 70 years. This fact makes it necessary to strive for a form that is both useful and pleasant to the eye.

There are a few approaches to bridge aesthetics. As always, it is necessary to divide viewers into those who are, by accident, in the vicinity of the bridge – let us call them tourists, those who are appropriately prepared on account of their professions, for example architects or artists, and

last but not least, civil engineers.

This differentiation stands for an average observation or even an impression of different subjects included in the same structure. In short, from the beginning a certain occupational, educational or cultural filter strongly influences the viewers' emotional reactions.

Aesthetics of road structures is a very broad issue, starting from aesthetics as a branch of philosophy (widely understood study of beauty, goodness and harmony) through aesthetics as the relation between the recipient or recipients of the work, i.e. road structures (elements of philosophy, psychology, sociology, sociology of art and aesthetic education), which further domains, such as transport psychology or the impact of route formation on drivers and other road users stem from, up to the aesthetics understood as the study of art and road structures as works of art, related to defining its values and evaluation criteria, connected with the essence of creation, its relation to the reality and the methods of artistic expression.

Due to limited space in the book, the authors use many abbreviations and references to the existing literature. We would like to encourage those who are interested in the subject to study the publications shown in the references in order to expand the knowledge and understanding of the issues discussed in this script.

## 1.2. History of beauty *(ALT)*

History of beauty is multidimensional and multidisciplinary; many historians of various fields, such as historians of philosophy, psychology, sociology, art (architecture, painting, and sculpture), music, literature, ecology, and finally engineers dealt with beauty.

This book is aimed at a student of eco-engineering; therefore, our area of interest is focused mainly on history of beauty related to road structures. In order to place the history of beauty in time, considering the aspect we are interested in, we have attached chronological table (see Tab. 1).

***Antic – Classicism***

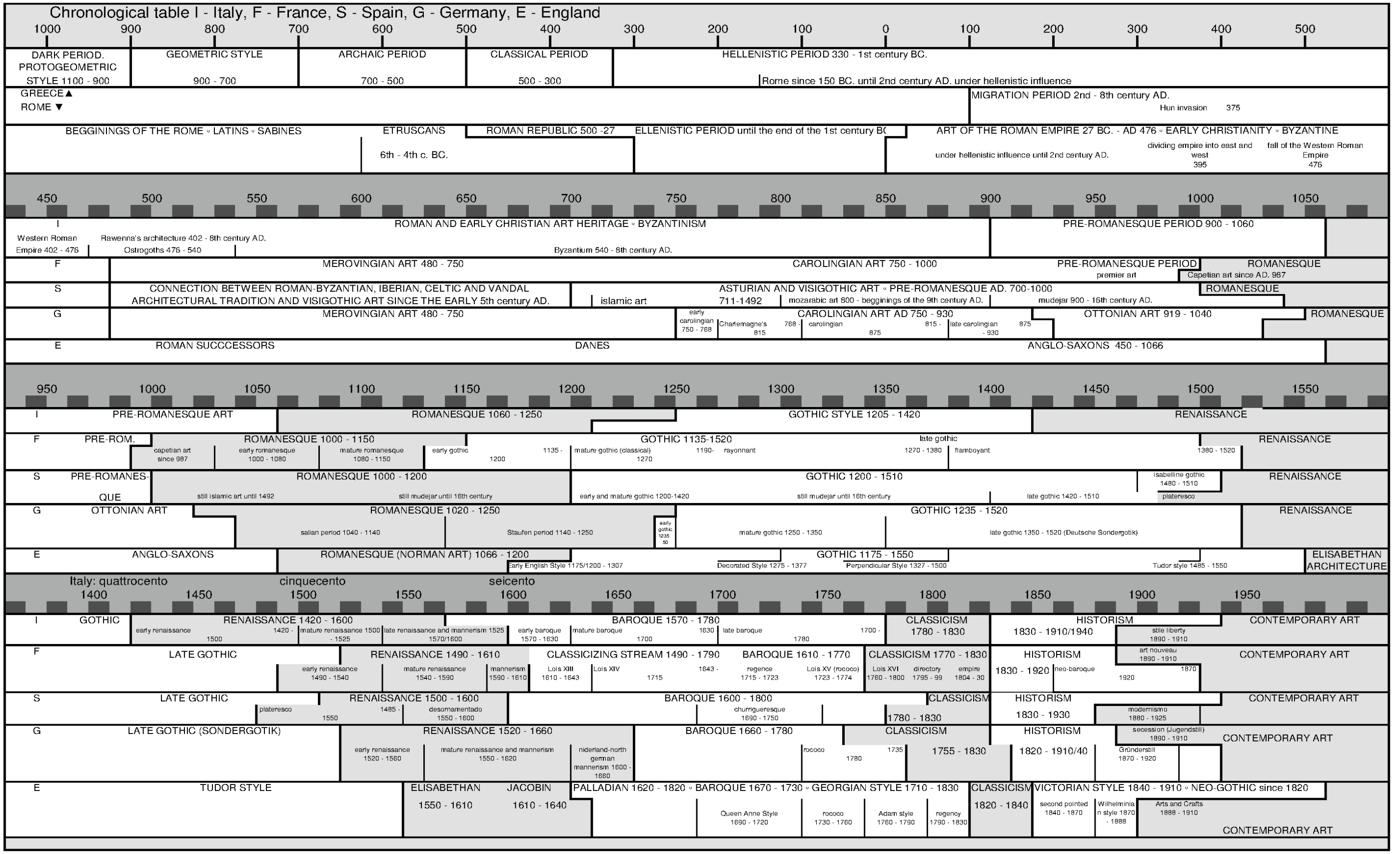
Ancient aesthetics as a branch of philosophy is the period from the 6$^{th}$ century BC until the 3$^{rd}$ century AD [Tatarkiewicz, 1985]. It constitutes the foundation of the European aesthetics. It is generally considered that the Hellenic period (from the 6$^{th}$ to the 3$^{rd}$ century BC) is attributable to the Greeks only and it is additionally divided into the following subperiods: archaic (from the 6$^{th}$ until the beginning of the 5$^{th}$ century BC) and classic (from the end of the 5$^{th}$ until the end of the 4$^{th}$ century BC) while the Hellenistic period (from the 3$^{rd}$ century BC until the 3$^{rd}$ century AD) took place with the participation of other nations. A slightly different chronology, which eco-engineers will be more familiar with, is used by the architecture historians [Koch, 1982]. The styles in architecture may be analysed starting from the 10$^{th}$ century BC known as the Greek Dark Ages, protogeometric style (1100–900 BC), followed by geometric style (900–700 BC) to the archaic period (700–500 BC), classical period (500–300 BC) and Hellenistic period (300 BC until the end of the 1$^{st}$ century BC), then the art of Imperium Romanum with Hellenic influences (until the 2$^{nd}$ century AD) and early Christianity until the collapse of the Western Roman Empire in 476 AD.

However, in the Mediterranean countries as Turkey, Syria, Iraq the term Roman Empire means different period. Its end is linked with the collapse of Eastern Roman Empire. Precisely its end was on Wednesday, 29 May 1453 when was the capture of the capital of the Byzantine Empire – Constantinople.

It is not possible to deny the existence of culture and, consequently, some aspects of aesthetics prior to the 10$^{th}$ century BC, which is admitted by the historians of both philosophy [Tatarkiewicz, 1985, 1998; Golaszewska, 1970, 1985] and architecture [Vitruviusz, 2004; Koch, 1982]. The Minoans, the Sumerians, the Egyptians: these civilisations are considered by most of the scientific world to be the first conscious and documented cultures, even though in the light of the discoveries made within the past 20 years[3] it might turn out that the culture of the Slavs will also be counted as one of the first (discoveries in Bronocice in Poland or the pyramids in Bosnia).

[3] http://philipcoppens.com/gobekli.html; http://www.philipcoppens.com/euro_pyrs.html; https://kristinasaid.wordpress.com/2012/10/18/naquatica-bosnia-pyramid-carbon-dated-25-thousand-years-old/; http://www.smithsonianmag.com/history/the-mystery-of-bosnias-ancient-pyramids-148990462/?c=y%3Fno-ist;

Table 1. Chronical table European Architectural Styles from antiquity to the present day [Koch, 1982].



When examining closely aesthetics of road structures we should start by looking at the creation of the first roads and bridges and by analysing to what extent their creation resulted from conscious and intended actions and whether and to what extent this was related to aesthetics.

The first road in Egypt which connected the Nile with the Pyramid of Cheops dates back to approx. 2600 BC[4]. The routes, set out and partly stabilised, which were even 14 meters wide existed in China as early as around 2300 BC. In the territory of present day Switzerland and the Netherlands there are traces, preserved until present, of roads strengthened with wooden logs, stone riprap or paved with flat stones and such roads date back to 1800–1600 BC. The chronicles mention that the first Sacred Road paved with stones existed in the ancient Babylon during the reign of king Sanherib, approximately 710 BC. In Poland we have examples of roads in Biskupin[5] made of wooden planks which date back to the 5th century BC. The excavations in the area of today's India indicate that in the late 4th and the early 3rd centuries BC there were few yet perfect roads. Such roads were even 21 metres wide with surfaces made of stone slabs or burnt brick joined with plaster or tar. We cannot also ignore Persian roads during the reign of Darius (521–485 BC) such as e.g. 2500 km long Royal Road which links Susa with Sardis or the road from Susa to Ecbatana and Persepolis. The ones who mostly developed the roads were the Romans, mainly due to their military needs. One of the oldest roads, Via Appia, which links Rome to Capua is approx. 198 km long and 8 metres wide. It was built around 312 BC. Others are Via Flaminia leading to Byzantium, Via Cassia and Via Aemilia leading to Milan. By approx. 120 BC the Romans built around 80 thousand kilometres of stone roads which were between 2.4 and 4.15 metres wide and 4.7 metres wide on the curves, and together with secondary roads they built around 300 thousand kilometres of roads in total – Fig. 1.2.1.

Floating/pontoon bridges and fixed-support bridges also flourished at the times when ancient empires while waging military campaigns were forced to lead their armies through rivers. The first historically knew fixed wooden bridge[6], on wooden piles to be precise [Orlowski, 2010] was built around 621 BC across the Tiber in Rome. It is considered that one of the first stone bridges was the 300 metres wide bridge built during the reign of Nabuchodonozor in Babylon around 600 BC across Euphrates River. According to the historical sources, the first bridge constructor was Mandrocles of Samos who built e.g. the pontoon bridge across the Bosporus for Darius the Great and his Persian army in 521 BC.

In Rome bridge construction became an organized activity and Collegium Pontificum was one of the most important state authorities. It is believed that there were approx. 40 thousand of Roman bridges and in ancient Rome 20% of state income was spent on roads and bridges per year [Glomb, 1997].

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[4] http://www.znaki-drogowe.pl/index.php?option=com_content&view=section&layout=blog&id=9& Itemid=97

[5] Archaeological Biskupin is situated on land belonging to the village Biskupin, Gniezno Lake District in north-western Poland.

[6] http://www.mostypolskie.pl/kalendarium,293,.html

It was also in Rome where the first legal act defining technical conditions of road construction was issued in 451 BC.

The Romans, however, adopted rules governing road construction from conquered nations. Until present underneath the surface of Roman roads there are traces of Etruscan routes. The Romans redeveloped and improved the existing roads, e.g. sections of Via Cassia. The Etruscans built mainly simple roads, of moderate width (4–5 metres wide) with drainage ditches on both sides, placing limestone slabs of 1.0 x 0.8 metres and 0.30 metres thick directly on the ground. Tuff, used by the Etruscans for road construction, is a very soft material, therefore ruts, preserved until now, appeared very quickly. The Greeks, as opposed to today's drivers, considered ruts to be a very useful thing and they used to cut them laboriously on the surfaces of their roads in order to enable overtaking vehicles on narrow roads, which would not be possible without previous determination of the travel path.


Figure 1.2.1. A map of the Roman Empire and Europe with road structures in 125 CE[7]

Construction of the first roads falls during the periods of pre-protogeometric style, dark and archaic styles and, finally, the classic style. Were the first roads and bridges constructors guided by the principles of aesthetics? In the case of roads it is difficult to state this clearly yet when it comes to bridges the issue is far more certain.

[7] https://upload.wikimedia.org/wikipedia/commons/d/df/Roman_Empire_125.svg

Aesthetics, as described in 1.1., is according to some a theory of beauty and according to others a theory of art. The ancient people dealt both with the theory of beauty and the science of art but treated both of them separately as they did not see any reason to combine them [Tatarkiewicz, 1985]. Nevertheless, in ancient times art and beauty grew closer and then drifted apart many times. When Aristotle[8] claimed that things are beautiful depending on whether they are of appropriate size, he combined beauty with the art, whereas Plato[9] who demanded that perspective should not be taken into account in order to present things the way they really are and not the way we see them practised the politics of art, and Democritus[10] who pointed out that the perspective changes in the eyes of the person who sees the shapes and colours of things contributed to the theory of art [Tatarkiewicz, 1985].

The written sources by Vitruvius [Vitruvius, 2004] speak about the principles of constructing main and secondary roads in towns. Such roads should be set out depending on the cardinal points of the compass and shielded against wind (8 types) which brings various illnesses. In *Ten Books on Architecture*[11] we can also find principles of location of town squares, forums and other public utility places, often related to road structures. Construction of such places should take into account the comfort and public benefit.

In ancient Rome road construction constituted an element of general civil engineering as there was no such profession as a road engineer. There was, however, the profession of a surveyor and *agrimensura*, i.e. *ars metendi agros,* was the art governed by definite principles and at first it was highly regarded by the ancient people; this regard, however, decreased with time. Roads were set out by surveyors who, depending on the period and on the tools they used, were called: *finitores*, *mensores*, *mensores agrari*, *decempedatores*, *agrimensores*, *gromatici*, *metatores* and military surveyors *castrorum metatores* [Pikulska-Robaszkiewicz, 1988]. The very process of setting out a road as well as the process of establishing towns was a ritual, initially of a religious nature called *limitatio*. At first a priest called *augur* performed the ritual and with time the ceremony became secularized and carried out by officers: surveyors. After issuing the Law of the Twelve Tables (which also included the legal act on roads) the roads were set out also by the servicemen and later this task was even given to servants and slaves.

The *limitatio* process itself consisted in defining an observation point called *templum* in the middle of the area where a town with roads and streets was to be created. At first *templum* was defined by a priest marking with a stick called *lituus* two intersecting lines on the ground and overhead in accordance with celestial signs. With time *agrimensores* guided by the position of the rising sun used for this purpose a tool called *groma, furra-*

[8] Aristotle, gr. Ἀριστοτέλης, Aristotelēs, (384–322 BC), the creator of a philosophical trend called Aristotelism, which had many forms in different eras.

[9] Plato (gr. Πλάτων, Plátōn, (427–347 BC); the creator of a philosophical system now called Platonic Idealism.

[10] Democritus of Abdera, gr. Δημόκριτος ὁ Ἀβδηρίτης (460–370 BC); philosopher and traveler, scientist, known as the "laughing philosopher".

[11] Ten Books On Architecture – writing of Vitruvius, the only ancient treatise on architecture, preserved in its entirety today.

*mentum or stella* [Pikulska-Robaszkiewicz, 1988]. The *groma* was positioned according to the cardinal points of the compass marking the axis from east to west – *decumanus*, and then *cardo* perpendicular to this axis. Along the *cardo* a public road was then set out; its width was even up to 30 feet (approx. 9.14 m) and the same road along the other axis, called *decumanus maximus* and *cardo maximus* respectively. From these the secondary roads were then set out.

Road also had their boundaries (the current delimitation lines of roads) defining a right-of-way. The setting out ritual, including the ritual of setting out roads, was probably adopted from the Etruscans, who in turn were under the Ionian influence. We should also mention setting out access (internal) roads which enable neighbours to access the land and which were also used to turn the plough while ploughing the field (today's squares for turning). In the literature the term *confinium* was adopted to describe them, determined by the lines called *linea finitima*, *finis* or *rigor*. In the field such lines were set out using boundary marks called *termini* [Pikulska-Robaszkiewicz, 1988].

Figure 1.2.2. Residues of Roman Road – Via de la Plata, near Caceres, Extremadura, Spain *(by SLK)*

Milestones used to be placed by the public roads. Such milestones, together with boundary marks, were under special legal protection. The Romans placed milestones at roadsides every Roman mile (1 478.5 m) and every 5 miles they put the so-called courrier stone, *lapides tabulari*, for orientation while travelling fast. Milestones were in the form of a cylinder, often with the rectangular base. The beginning of the road was engraved in them, in Italy the starting point was Rome and in other provinces it was the capital of province or the closest important city. Until now around 4000 Roman milestones were preserved and the oldest comes from the 3rd century BC. Augustus placed on Forum Romanum golden milestone, *milliarium aureum*, marking the exact centre of the city, *umbilicus urbis* (navel). This was the starting point of the largest roads of the empire: Via de la Plata (Fig. 1.2.2), Via Aurelia, Via Ostiensis, Via Flaminia, Via Salaria and this is where Via Sacra went through (all the roads lead to Rome).

### *Byzantium*

The period in history, also in the history of beauty, called Byzantium, is inextricably linked to the existence of the Byzantine Empire[12] and its circle of influence. Historians[13] do not agree on the exact date of the beginning and the end of Byzantium [Haldon, 2003]. It is usually considered that the prevalence of the Byzantine Empire is the period from 324 to 1453 (from naming Constantinople as the capital of the Empire, to the beginning of the Ottoman Empire) [Koch, 1982]. The Byzantine architecture was strongly associated with the Christian ideology and the dynasties then in power, and so it is divided into:

- The first period from the foundation of Constantinople to the collapse of iconoclasm in 843, which is often called the Early Byzantine Period;
- The second period (867-1204), which is the renaissance of architecture, and more generally of Byzantine art, ends with the seizure of Constantinople by the Crusaders in 1204; it is also called the Middle Byzantine Period;
- The third period, linked with the restoration of the Empire (1261–1453), ending with the Conquest of Constantinople by the Turks, is also called the Late Byzantine Period.

The art and architecture of this period were related to the process of Hellenization and progressing Christianization. The historical background, including wars and crusades also exerted strong influence. The art of this period is strongly religious, but the Byzantines considered themselves Greeks, hence they largely maintained the Hellenic traditions, forms and concepts of art. This period saw the structural refinement of the Roman, early Christian and Hellenic, as well as Oriental, particularly Persian techniques and traditions. Along with the territorial expansion of the Byzantine Empire, its area of influence was extended to Italy and North Africa and is noticeable in the architecture of Armenia, Georgia, Russia and Poland. The Venetian Republic, the territory of present day Bulgaria, Serbia and Macedonia were under the influence of Byzantine art.

The churches (e.g. Hagia Sophia[14]), the orthodox churches, the palace in Constantinople[15], baptisteries (of the Orthodox Christians and Arians in Ravenna) are the architectural legacy of the Byzantine Empire.

Although the construction of road structures of this period did not bring any substantial progress in comparison with the Roman times, it is worth mentioning the Ponte Vecchio (Fig. 1.2.3.) on the Arno river (1335-1345) designed by Neri di Fioravante[16] and Taddeo Gaddi[17].

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[12] historiographical term used since the nineteenth century to describe medieval Roman Empire with its capital in Constantinople.

[13] https://pl.wikipedia.org/wiki/Cesarstwo_Bizanty%C5%84skie; https://pl.wikipedia.org/wiki/Sztuka_bizanty%C5 %84ska; https://pl.wikipedia.org/wiki/Architektura_bizanty%C5%84ska.

[14] Hagia Sophia (gr. Ἁγία Σοφία, turns. Ayasofya). In the past, the Christian church, then a mosque.

[15] Great Palace of Constantinople (Greek: Μέγα Παλάτιον) – the imperial palace which served as the center of the imperial administration from the year 330 to 1081.

[16] Neri di Fioravante Fioravanti (Pistoia, ... – Florence, 1374), Italian architect of the fourteenth century, active in Florence and Tuscany.

[17] Taddeo Gaddi (b. Approx. 1300, d. 1366) – Italian painter of the Proto-Renaissance period, the author of murals in Florence, Poppi, Pistoia and Pisa and easel paintings.

Figure 1.2.3. Ponte Vecchio (Old Bridge) in Florence, Italy (*by ALT*)

The bridge was built of stone blocks at the site where a wooden bridge was built during Roman times. Its structure was composed of three spans, 28, 30 and 27 meters wide respectively, supported by massive pillars which held up a 32 meters wide slab, sectional stone vaults with the f/l ratio equal to 1/7.5 and spans of 27.0 + 30.0 + 27.0 on high pillars, with the pillar thickness to arch clearance ratio of 1:5, and with shops, stalls and later workshops of jewelers and goldsmiths, from whom it took its name.

During this period it is worth to take note of bridge engineering achievements in other parts of the world, albeit not directly related to Byzantium, i.e. bridges suspended on iron chains in India, about the year 400 CE or a stone arch bridge in Chao-Zhou in China (610 CE).

The Byzantine aesthetics can be summarized by three theses [Tatarkiewicz, 1988]:

- **The first** one being the dualism and religious view of the world. The first world is divine, spiritual, perfect and the other world is earthly, material, imperfect, dark and menacing. The latter is formed in the likeness of the first.
- **The second** thesis claims that the material world is not quite evil, if God came down to it and stayed among people.
- **The third** thesis claims that man lives on earth, but his life belongs to the divine world.

The aesthetics of the Eastern Empire on the one hand was connected directly to antiquity (Plato's Academy[18] existed up to the 6th century, and on the other – it was strongly related to the Holy Scriptures and the "beauty of creation". The concept of "beauty" (gr. καλὸς) can be found in the Greek version of the Scriptures, the Septuagint[19]. For the Greeks objects had direct beauty, evidenced by the properties of things. Beauty for the Greeks was visual, related to harmony, it lay in perfect proportions, form, in combining

[18] Plato's Academy - philosophical school founded in 387 BC by Plato.

[19] Septuagint (Latin. Seventy, marked a Roman number indicating the LXX 70, in critical editions by the symbol 𝔖 – the first translation of the Old Testament from Hebrew and Aramaic into Greek.

things, it was static, full of peace and balance. The Greek thesis was that beauty is inherent in nature, they sculpted their gods.

For the Israelites, according to the Hebrew concept, “beauty” (hebr. )was indirect and symbolic. Beauty was manifested by action, the feeling it awakened in the subject. Beauty was a matter of different senses (sight, hearing, taste, smell), it was synonymous with a sensual enticement, it was a property of separate components, it lay in not combining things, was related to purity, oneness of color, not mixing. Beauty was represented by the intensity of the property, color, light, scent, sound, it lay in what is alive and active, in grace and strength. The beauty of nature played a negligible role in Israel, there was a prohibition on representation of God, because he was conceived without an image [Tatarkiewicz, 1988].

***Medieval – Gothic***

After the death in 395 CE of Theodosius I (the Great)[20], the last emperor ruling over both the eastern and western part of the Roman empire the political division into the East and West was established. Whereas in Byzantium the earlier achievements of ancient Rome were continued, adapting them to early Christianity, in the west it was the barbarian tribes that had a significant impact on architecture and art. New, hitherto unknown West-Nordic forms were established, which defined the whole European architecture for a long time. The medieval architecture in Western Europe is divided into: pre-Romanesque, Romanesque and Gothic. The pre-Romanesque period is defined by the Merovingian and Carolingian art in France and Germany (in the latter also by the Ottonian art), Celtic, Vandalian, Asturian and Visigothic art in Spain, Anglo-Saxon — in England (Table 1). Romanism prevails throughout Europe, with Norman art in the territory of today’s England, similarly to Gothic art. The Middle Ages, due to decentralization and privatization of public authority is the period of gradual destruction of the road network [Buszma, Domaradzki, Rolla, 1969; Batson, 1971]. Maintenance of ancient routes was discontinued and new ones were not built. Bridges were also badly affected by destruction. The medieval highways bypassed the more difficult places, looking for a more convenient ford or ferry crossing. The places of crossing are commemorated until today by names: English place names ending in -ford (e.g. Oxford), German ones ending in -furt, or Brodnica in Poland. Small, individual political communities replaced the network of Roman settlements, the feudal system which which delegated the problem of maintenance of the royal highway to individual parishes, and repairs to subjects according under the rule of corvee (e.g. in England) which was often shunned, contributing to the collapse of the road network throughout almost the whole of Europe [Kopczynski, 2004]. Some medieval cities or abbeys in Europe undertook some efforts to improve the condition of roads, but they were insignificant against the enormity of expenditures required to improve the condition of the neglected road network [Buszma, Domaradzki, Rolla, 1969].

[20] Theodosius I, Flavius Theodosius, Theodosius I (b. 347, d. 395) – the last emperor who ruled both the eastern and western part of the Roman Empire.

Toll gates became the permanent element of the road landscape, where tolls were collected. This was done by all road owners: rulers, princes and the church. The practice was beneficial, because the profits went to the pockets of collectors who did not care about the poor technical condition of roads, and sometimes even tolerating the poor technical condition of roads was lucrative, because the ownership of goods which fell from the cart to the ground transferred to the road owner.

Moreover in the Middle Ages people traveled mainly on foot or on horseback, at slow speeds, which generally made traveling a costly enterprise (reportedly transporting goods was more expensive than the value of the goods themselves by half) [Kopczynski, 2004]. Women and clergy used sedan chairs to travel.

Only the formation of the Benedictine order in the 6th century CE, which was the first that in addition to spiritual matters was also occupied with the earthly ones, including construction of roads and bridges, as well as the era of the reign of Charlemagne[21] in the late 8th and the early 9th centuries – the period of intellectual revival (also called the "Carolingian revival") – contributed to some improvement of the situation of road structures. Charlemagne founded a Palace School at Aachen headed by the most eminent scholar of that time: Alcuin, an Anglo-Saxon monk. The king was also surrounded by such minds as: Angilbert, Ansigis and finally Einhart who focused his efforts "*ad institutionem viarum et pontium*" (on the construction of roads and bridges). Under his supervisions the so called building guilds were formed and developed in Fulda, Paderborn, Metz, Osnabruck, Lyon, Tours, Magdeburg and other places. By order of Charlemagne (chapter *Epistola de litteris colendis*) schools were also founded at parish churches and monasteries. People could read there and get acquainted with the works of Greeks and Romans, among others, those of Vitruvius [Glomb, 2004]. On the basis of "*Ten Books about Architecture*" they began to rebuild some of the Roman roads, new stone bridges were also built. Nearly 600 stone bridges were built in the Middle Ages, while five of the greatest bridge structures of the world at that time were: The Steiner Brücke stone bridge on the Danube river in Regensburg of 1135 CE, the Old London Bridge, built between 1176 and 1208 in London, the Judith Bridge in Prague across Vltava (Fig. 1.2.4.), built in around 1171, the bridge on the Rhone in Avignon, built in the years 1179–1188, half of which survived until our times, and the bridge over the Elbe built in Dresden in 1119 [Glomb, 1997]. Most stone bridges of the Middle Ages are arch structures. In the St. Benezet bridge on the Rhone we can see basket arches of changing curvature, in the Scaliger bridge across the Adige in Verona (1354–1356), designed by Bevilacqua, partial semi-circular arches were used of variable height and span: 24.0 + 28.57 + 48.7 m respectively. Some time between 1281 and 1390 the oldest stone bridge in Poland was built on the Młynówka River in Kłodzko [Biliszczuk et al., 2000].

[21] Charles the Great (lat. Carolus Magnus, fr. Charlemagne, Ger. Karl der Grosse, 742–814). He created the first European empire after the fall of the Roman Empire.


Figure 1.2.4. The Charles Bridge, Judith Bridge, Czech: Karlův Most (*by ALT*)

The factors contributing to the improvement of the road network were huge migrations related to pilgrimages and Crusades. Through Crusades the Europeans of that time were exposed to the beauty, richness and high technical civilization of the East. In the late eleventh and the early twelfth centuries began the so-called medieval humanism, with outstanding minds of European culture, such as: St. Bernard, St. Francis of Assisi, St. Thomas Aquinas, Abelard, and Roger Bacon. Orders of the so called "bridge brethren" (fratres pontis) were formed, which in 1189 received from pope Clement III a special decree authorizing their existence, and in 1198 his successor, pope Innocent III bestowed numerous privileges on them. As a result of their activity many bridges were built in Medieval Europe. Associations of craftsmen were formed, and later first construction companies (e.g. the late 11th and the early 12th centuries in Lombardy), under the supervision of cathedral chapters or cities (in modern terms, the investors) or even self-financing, backed by lawyers, merchants, but also technicians [Glomb, 2004].

The concept of beauty in the Middle Ages was associated with truth and goodness, and the world – created by God – was perceived as a purposeful, harmonious and therefore beautiful creation. Superiority of the spiritual over the material goods was adhered to, believing that man is called to the continuous effort of self-improvement. The idea of theocentrism, subordinating all human matters to God, dictated recognition of various phenomena of the world as perfect signs from the Creator. Behind their literal meanings, deeper, hidden content was also perceived.

***Renaissance***

Renaissance (fr. renaissance, it. rinascita – "rebirth") started circa 1492 (when Christopher Columbus discovered America) and lasted throughout the 15th and the 16th centuries. The Renaissance aesthetics put less emphasis on the unity of beautiful objects than the classical culture. It was fascinated with the antiquity and brought about the rebirth of sciences, humanism, secularization of social life, individualism and higher appreciation of the artist's role. In his *Book of the Courtier*, Castiglione wrote about Leonardo, Mantegna, Raphael, Michaelangelo and Giorgione that "*each of them is unlike any other, but they all share the perfection of style*". When relating the history of his works, Leonardo da Vinci wrote that "*the art of building... in Italy reached a perfect maturity and beauty*", and that the Romans "*had created such a perfect art of building that it had nothing mysterious, concealed or vague*", nothing that would be "*in discord with the art itself*". In another passage, da Vinci equates "beautiful" with "absolute", as well as with "faultless" and "as if divine" in the Italian translation. These were synonyms for beauty.

The Renaissance was characterised by its fascination with the Antique period, the revival of science, humanism, secularization of social life, individualism and appreciation of the role of an artist. Roman monuments constituted the model of ideal proportions and divisions in architecture. The central domed buildings were innovations introduced by Bramante[22]. Antique proportions were implemented in architecture through the use of columns and entablature. Popular structures included the triumphal arch and the portico with a triangular tympanum. Elements widely used in architecture comprised the semicircular arch, arcaded colonnades, simple entablatures, domes, barrel vaults or cross vaults and coffered ceiling.

The Renaissance period did not result in any large improvements in road construction. The humanist thinkers pointed back to the achievements of the Roman road engineering only theoretically, as the costly solutions dating back to the antiquity could not be implemented in practice. Furthermore, the most frequent modes of travelling were on horseback and on foot, and as such they did not require any significant improvement of the high road.

In the 16th century, as part of road enhancement initiatives, the *Scharwerk* was introduced. It was a mandatory public labour usually performed by the locals. In 1557, the Polish magistrate collected one Groschen from a person with a loaded cart for the street repairs based on the privilege granted by King Sigismund Augustus. Moreover, the Cobblestone Commission started functioning in Warsaw in 1644. Owing to the support of King Augustus III, it renovated 18 streets in the city in 1740. However, it was only a drop in the ocean, considering the general condition of roads across the whole country. The situation in France was not any better. For instance, only three carriages could be seen in Paris in the mid-16th century: the first belonged to King Henry II, the second to Diane de Poitiers, the royal favourite, and the third to a man who was unable to mount a horse due to obesity. Other European cities were similar in this respect. On the other hand, the small number of carriages was related to the condition of the roads. Travellers were exposed to great risk, firstly because of the pace (2 km/h) and secondly because of the tract condition [Kopczynski, 2004].

[22] Donato Bramante (1444 –1514) – Italian architect and painter.

As regards bridges, the situation was slightly better. Bridge construction started following scientific principles. Leonardo da Vinci[23] was the first to describe the mechanics of the structures, the linear perspective was discovered and it created the basis for the new concept of space perception that combined art and science. Andrea Palladio[24] developed new spatial construction models in the form of arch trusses and hammer-beam structures.

One of his significant works is Ponte del Alpini (Fig. 1.2.5.) on the Brenta river in Bassano del Grapa (1568), with wooden hammer-beam construction and the supports design based on the research of da Vinci related to the impact of river swirls.

Ammanati's[25] Ponte Santa Trinia on the river Arno in Florence (1566–1569) is the first example of using the elliptical arch with the f/l = 1/7 ratio. The platform is topped with an impressive stone balustrade joined in the headstone with the vault by cartouches on both sides, thus contributing to the overall elegance of the structure.

The famous Ponte Rialto (1587–1592) over the Canal Grande in Venice was designed by Antonio da Ponte[26], who was, then 75 years old. The arch is heightened to facilitate sailing and it has a span of 29.56 m, with the load resting on the massive abutments (made of the Istrian stone, as is the vault), each of which sits on 2 thousand wooden poles squeezed into the soggy ground. The bridge is 22 meters wide, as many other bridges from the period, and it carries stores, stalls and currency exchange booths.

The bridge over the Seine built in 1507–1512 by Fra Giocondo had residential building up to the four storeys high (it was demolished in 1853).

Figure 1.2.5. Ponte del Alpini on the Brenta river in Bassano del Grapa (*by ALT*)

[23] Leonardo di ser Piero da Vinci, more commonly Leonardo da Vinci (1452–1519) was an Italian polymath.

[24] Andrea Palladio (1508–1580), Italian architect influenced by Vitruvius. His teachings, summarized in the architectural treatise, The Four Books of Architecture, gained him wide recognition.

[25] Bartolomeo Ammannati (1511–1592), Italian architect and sculptor.

[26] Antonio da Ponte (1512–1595) was a Swiss-born Venetian architect and engineer, most famous for his rebuilding of the Rialto Bridge in Venice.

***Baroque***

Baroque (Portuguese: *barocco* – "a pearl with irregular shape") is one of the main periods in the development of European culture, lasting from the end of the 16th century to the 18th century. It was the time when the attitude towards beauty in art changed. Beauty became less significant, less definite and less objective. Abandoning the classical perfect canons and the accidental beauty of symmetry and glamour for the sake of disharmony, asymmetry, dissonance, irregularity, lack of proportion and moderation, dark colours, vagueness, non-transparency, mystery, intricacy: that is a short definition of the style. Two key movements developed in this period and laid foundations for the Enlightenment. Firstly, rationalism, which assumed that wisdom and knowledge can be gained only through the power of reason. Its famous dictum coined by Descartes[27] was: "*Cogito ergo sum*" (I think therefore I am). Secondly, empiricism, which stressed the senses and experience of the world, with its seminal work being *A Treatise of Human Nature* by David Hume[28].

Figure 1.2.6. The Baroque bridge, Zdar nad Sázavou, (*by Jerzy Strzelecki*[29])

Sciences developed rapidly at that time, though one cannot say the same about the construction of bridges. Universities were established (e.g. the Academy of Sciences in Paris in 1666) that educated future engineers. Nonetheless, bridges were still made by such people as Ulrich Grubenmann, a carpenter, who designed and constructed bridges over the Rhine and many others, including (in 1758) the then largest wooden arch (120 m) in the world [Glomb, 1997]. Considering the important bridges of that time, one must mention Perronet, the master of stone vaults: Pont de Neuilly (1772) and Pont de la Concorde, both over the Seine.

[27] René Descartes (1596–1650) – French philosopher, mathematician and physicist, one of the greatest scholars of the seventeenth century, also considered the father of modern philosophy.

[28] David Hume (1711–1776) – Scottish philosopher, historian and economist, representative of deism, in economics supporter of free trade.

[29] https://commons.wikimedia.org/wiki/File:Baroquebridge-ZdarnadS%C3%A1zavou%28js%29.jpg

The 18th century is also the time of the partitions of Poland and of the bridges (at least seven) built by Johann Gross[30], the greatest engineer in Galicia, including the stretched construction bridge over the Biala river near Tarnow (1781–1782) [Glomb, 1997]. In 1792, an impressive stone bridge was built over the Bobr river in Plakowice near Luban [Biliszczuk i in., 2000].

The Baroque bridge on the road from Zdar nad Sázavou, now Czechia, was built in the days of the abbot Bernard Hennet. Chronograms on eight statues of saints provide details of their creation time. There is the year 1761 on seven of them, and 1766 on the last one (St. Methodius). The sculptor of these statues is unknown (Fig. 1.2.6).

Wilhelm Leibniz[31] and Isaac Newton[32] developed the integral and differential calculus which proved very useful in calculating the key dimensions of buildings. The eminent scientists of the time included: the Bernouli brothers, Euler, Coulomb, Lagrange, Laplace, Navier, and Cauchy, who created the principles of the optimal shape for buildings. Such sciences as mathematics, physics and chemistry thrived simultaneously, thereby contributing to the development of new building materials, iron and concrete, as well as the principles of their rational application in construction, including bridge engineering. It was the drive behind the first industrial revolution, when the traditional brittle materials (stone, brick) began to be replaced by ductile materials (iron, steel) and artificial stone (concrete) that facilitated the formation of any shape. It resulted in beam, frame, hanging, suspended and ribbon structures in bridge engineering. In 1747, the first engineering school was established in Paris – École des Ponts et Chaussées.

***Steel – Reinforced concrete impast***

The second half of the 18th century and the 19th century constitute the era of iron in the construction industry [Thullie, 1921]. Stone bridges were not completely abandoned (e.g. the Ellesmere Canal over the river Dee built by Thomas Telford or the stone bridge over the Kaczawa river in Złotoryja), but at the same time Darby and Brunel started constructing iron bridges in England [Glomb, 1997]. On 10 November 1796, the first modern furnace on the continent started operating at the steelworks in Gliwice, Poland. As a result, the first iron bridge in Europe (and the second in the world) was built in Lazany, over the Strzegomka river [Biliszczuk and ot., 2000]. A significant symbol of that period is also the cast-iron bridge on the Severn river in eastern Wales – the Coalbrookdale Bridge from 1779. It was also in Wales that the Menai Straits Bridge was constructed (176 meters, suspended arch!), one of the largest bridge structures of the 19th century. George and Robert Stephenson built the first rail and road bridge in the world: the King of the Railway Structures (1849).

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[30] Johann Gross (1733–1805), engineer. In the years 1777 to 1779 built a bridge strut on the San River in Przemysl. In the years 1773–1805 Gross built in Galicia over 3,000 bridges and culverts.

[31] Gottfried Wilhelm Leibniz, also known under the name Leibniz (1646–1716) – German polymath philosopher, mathematician, lawyer, engineer-mechanic, physicist, historian and diplomat. Leibniz contributed to the development of calculus.

[32] Isaac Newton (1642–1727). In his famous work Philosophiæ Naturalis Principia Mathematica (1687) introduced the law of universal gravitation and the laws of motion, the underlying classical mechanics.

The 19th century is the golden age of suspension bridges. Within 17 years, from 1825, when Seguin built the Tain Tournon bridge in France, to 1842, when Charles Ellet completed the Fairmount Bridge in Pennsylvania, almost 150 suspension bridges appeared around the world, including 100 in France and nearly 20 in England [Glomb, 1997]. Of course, it does not mean that no bridges were built east of the Seine. The Holy Alliance of the Hapsburgs, the Romanovs and the Bourbons led to the first permanent bridge over the Danube (connecting Buda and Pest) since the Roman times. At the same time, Stanislaw Walerianowicz Kierbedz, an engineer, a scholar and an official, constructed the first permanent bridge over the Neva river and the first large iron bridge in Russia. In 1863, during the January Uprising, he also built a bridge over the Vistula river in Warsaw, along the line of the Castle Square.

The 20th century is a period of rapid development of technology, a time of great challenges and gigantic bridges. Examples include: the Brooklyn Bridge by Roebling, a philosopher and an engineer, as well as the Queensboro Bridge (1909) by Lidental, both on the East River. One must also mention one hundred bridges built by Gustave Eiffel (the man behind the Tower and the Statue of Liberty), e.g. the bridge in Busseau, Neuvial, Bouble, Rouzat, Bellon, and Pia Maria in Oporto. It was also the time of great catastrophes in the bridge construction industry, such as those on the Quebec river. The first one was caused by Theodore Cooper in August 1907, when the entire structure of the southern part collapsed and 20,000 tons of steel fell into the river [Glomb, 1997]. The second one, much smaller in scale, was blamed on Rudolf Mierzejewski. It happened in the summer of 1916, in the final assembly phase, when the entire suspended section (5,200 tons) ended up in the river. 95 people were killed and over 25,000 tons of steel were lost [Glomb, 1988]. One cannot forget about the great bridges of America, e.g. Modrzejewski's 6 bridges over the Mississippi, Missouri (Delaware, Ohio), The Saint Lawrence River in Quebec, on the Great Lakes (Detroit) and over the San Francisco Bay (Trans-Bay Bridge).

The 20th century brought a new, wider and more versatile approach to bridge construction. The theory and practice of bridge engineering were at a high level, other disciplines of science thrived and people's expectations were increasingly higher. This is well exemplified in the Golden Gate Bridge (San Francisco): the initial study took 11 years, the team of 100 engineers continued the design works for over 4 years, while the construction itself lasted 5 years [Glomb, 1997].

Apart from such large-scale projects intended for public use, one should also mention other type of works, artistic in their form and designed to be used by small groups of people, e.g. the Salina-Tobel-Brücke by Maillart, a bridge for 50 people from the nearby village [Glomb, 1997]. This leads to a conclusion that technical goals were not always the top priorities. People as users and the natural environment were often in the centre of attention. It was the period when steel structures were also erected, e.g. the bridge over the Stuldwia River near Lowicz (1929) built by Stefan Bryla. It is a monument of technology and the first welded construction bridge in the world.

Other steel bridges from this period include: the Washington Bridge (1930), at the time the largest steel bridge in the world, built by Ammann. In the 1930's, owing to the great achievements of Eugène Freyssinet, stressed structures began to be used for bridges, which accelerated the technical development and reduced the construction costs.

Figure 1.2.7. Pont Gisclar over the Tet river in France – railway suspension bridge; source[33]

Bridges from that period include: the Mooney Mooney Creek, completed in 1986 in Calga-Somersby in Australia, the Tiger Gate-2 (1997) in China, and the Sundoy in Norway, completed in 2000. Many bridges of the 20th century are suspension bridges, e.g.: Pont Gisclar over the Tet river in France (Fig. 1.2.7.), the Grunwaldzki bridge over the Odra river in Wrocław (1910), the Manhattan Bridge in New York as well as the Akashi-Kaikyo Bridge and Seto Ohashi in Japan [Bennett, 1999].

***Modernism and Eclectism***

The person who coined the term "modern art" was probably Joris-Karl Huysman[34] in 1883. In the history of art the time frame of modernism spans from the 1960s of the 19th century (impressionism) to 1970s of the 20th century (conceptualism). Modern art is closely related to modernism in philosophy and to the avant-garde. Modernism (also called functionalism or rationalism) in architecture was not a uniform phenomenon and did not have an unambiguous ideology (this was discussed in more detail in chapter 1.3). Within the architecture of modernism we have both sceptical humanism (e.g. Mies van der Rohe[35]), and radical communism (e.g. H. Meyer [36]). The best known manifestos

[33] https://commons.wikimedia.org/wiki/File:Pont_gisclar_082004-3.jpg#filehistory

[34] Joris-Karl Huysmans, (1848–1907). French writer, art critic, novelist.

[35] Ludwig Mies van der Rohe, (1886–1969) – German modernist architect.

[36] Hannes Meyer (1889–1954) – Swiss modernist architect and urban planner.

of modernism are Le Corbusier's[37] Five Points of Architecture and *Charte d'Athènes*[38]. In architecture modernism appeared in opposition to the aesthetics of historicism of the 19th century and to the secession which followed.

Eclecticism and secession both formed a context for modernism. Eclecticism, from the Greek word *eklektikós* – selective, consists in combining freely various, often conflicting, styles. From the second half of the 19th century until the beginning of the 20th century eclecticism was present in the form of historicism and covered the entire Europe and North America. Historicism consisted in imitation of the past designs and foregoing the attempts to create a style which corresponds to the current historical and social conditions. The interest in the architectural past coincided with the development of history studies. From the beginning of the 19th century intensive works on the history of architecture have been carried out. The researchers started describing, differentiating and dating buildings (research on Romanesque and Gothic styles). This research was the base for architects who rediscovered neo-styles around the world (neo-Romanesque, neo-Gothic, neo-Renaissance and neo-Baroque). Gradually, the initial romantic historicism, which superseded classicism, together with neo-Gothic and arcade styles were in turn superseded by neo-Renaissance. The neo-Renaissance with time grew closer to neo-Baroque with numerous bay windows, risalits, domes and balconies accompanied by striving for monumentality, with elements of flower ornaments which indicate the emerging secession.

In architecture secession developed in 1890–1925 and was a result of seeking to free the form from pure imitation of the previous times. In Poland secession was adopted slightly earlier than in most European countries, mainly due to the influence of German, Austrian and French architecture in Poland. The earliest tendencies of the *Art Nouveau* were visible in France, partly under the influence of *École des beaux-arts*[39], Viollet-le-Duca[40]. Avant-garde pursuit of development with ethical and intellectual basis caused lack of stylistic uniformity of the initial secession. The attempt to create a new style without any reference to history but only on the basis of aesthetic motivation and inspiration of the creator contributed to the occurrence of certain forms of abstraction which, however, also had rich ornamentation. This in turn was a result of contact with Japanese calligraphy and graphics. Among the *Art Nouveau* ornamentation we can find stylized plants, figures and masks of long-haired women, forms resembling drapes or leather, reliefs sometimes occupy the entire area of exterior walls. Ornaments also include the detailed finishing elements of the building, such as door handles or balustrades of the stairs. Except for the leading architects, the style was basically limited to decoration, the issue of function and construction was left to the construction engineers. This is visible in particular in residential buildings where urban planning solutions and layouts remained compliant with those from

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[37] Le Corbusier, actually Charles-Édouard Jeanneret-Gris, (1887–1965). French architect and city planner. Creator of a modular system – Modulor.

[38] adopted at the XIV Congrès international d'architecture moderne (CIAM) Congress in Athens in 1933.

[39] École nationale supérieure des Beaux-Arts de Paris, ENSBA, founded in 1648.

[40] Eugène Emmanuel Viollet-le-Duc (1814–1879) – French architect, art historian.

the 19th century and the public utility buildings, albeit innovative, used romantic themes as well as elements which were both neo-Romanesque and neo-Gothic.

The occurrence of new materials, such as iron, glass or concrete, as well as new techniques such as iron and steel constructions contributed to the improvement of statistical calculations in engineering, which in turn enabled wide-scale application of prefabricated elements and glass [Koch, 1982]. The professions of engineer and architects were also separated, which was visible e.g. in the creation of the following higher education institutions: the Society of Engineers in London (1793) and *École Polytechnique* in Paris (1794) – for engineers, *École des beaux-arts* in Paris (1806) – for architects.

Some examples of road structures belonging to the aforementioned trends are:

- Tower Bridge (1886–1894) in London with cast iron pylons hidden in Victorian, neo--Gothic towers (Fig. 1.2.8.);
- bridge over the Elbe river (1884–1888) in Hamburg with neo-Gothic entrance gates and cast iron construction of the bridge which together form a synthesis of historicism architecture and engineering art (here the historic forms play the role of symbolic domination over pure function).

Figure 1.2.8. Tower Bridge over Tamiza River in London (*by Diego Delso*[41])

## 1.3. Architecture of Adolf Loos as a turning point in the understanding of beauty – towards pure art (*ALT*)

The first manifesto of the emerging modern movement, the so-called modernism, for which the context was provided by the eclecticism and secession, was the paper of

[41] https://commons.wikimedia.org/wiki/File:Puente_de_la_Torre,_Londres,_Inglaterra,_2014-08-11,_DD_092.JPG

Adolf Loos presented in 1910 entitled "*Ornament und Verbrechen*"[42]. Adolf Loos, born on 10 December 1870 in Brno, an Austrian architect, theoretician and publicist, is considered to be the pioneer of modernism and of modern architecture. Good proportions, harmony, rejection of unnecessary ornaments, pure art, minimalism: these are the core theses of his theory of aesthetics[43]. Famous sentences: "*Ornament is a crime*" (Adolf Loos), "*Less is more*" (Mies van der Rohe), "*Form follows function*" (Sullivan) – they all constitute mottoes of new principles of art from this period. Original and provocative essays written by this critic of the eclectic style from the turn of the centuries laid the foundations of the modernist revolution in architecture. Loos criticised the aesthetics of that time, in particular *Art Nouveau*. He pointed out negative moral, economic and sociological aspects of using rich ornamentation. While proving aimlessness of ornaments, he believed that their sources were in the expression of animal instincts of indigenous peoples. He claimed that the original functions of the ornament were adopted by the art and that beauty defines the accuracy and refinement of pure material without ornaments. For him ornament was combined with lost capital; he stated that the styles of ornaments quickly become out of fashion and lose their value. He was against wasting work, time and money on making unnecessary ornaments. He wrote about the morality of an informed consumer and claimed that freedom from ornament is a symbol of not degenerated mind[44].

The principles of the modernist aesthetics assumed on the one hand deep humanism and prosocial attitude, i.e. serving people, equal access to the sun, air and greenery for everyone. The development of road networks was to provide such access everywhere and to everyone. The buildings departed from ostentation, i.e. the contrast between the façade and the interior of the building, taking into account proper lighting of apartments, suitable positioning of buildings in relation to the cardinal points of the compass, which was to provide better, healthier and more hygienic life. In road structures, which were created as a consequence of rapid development of engineering art, care was taken to ensure that transport routes connected, not divided, and that the greenery constituted boundaries isolating them from urban areas. There were concepts of starry and linear road system (Le Corbusier45, Aalto46, Niemeyer47), oriented along vital axes, their direction depending on the natural topography and wind direction, which in certain aspects was a return to the principles of ancient classicism.

On the other hand, though, modernism with its rigorous and conventional design and technocracy, which led to alienation, isolation and even to social pathologies, brought about strong anti-modernist tendencies (Team Ten[48], Smithsons). Their supporters argued

[42] Loos's essay emergence dates back to 1908, first published in 1913 in French in the magazine "Cahiers d'aujourd'hui" (No. 5/1913), first published in German in 1929.

[43] Loos A., Opel A., Ornament and Crime: Selected Essays. Ariadne Press, 1998.

[44] Banham R., *Theory and Design in the First Machine Age. Praeger. 1960.*

[45] Le Corbusier, as above.

[46] Hugo Alvar Henrik Aalto (1898–1976) – Finnish modernist architect and an industrial designer.

[47] Oscar Niemeyer (1907–2012) – Brazilian architect, representative of the world modernist architecture.

[48] Team X (alternate spellings Team This and Team 10) – an international architectural group of late modernism. The group was composed of architects, who presented the CIAM in 1954 and different from the hitherto dominant

that the modernists are monotonous, ignore the needs of the user and are far from cultural roots of men.

Some[49] state that the ideas of Loos were not in reality his own invention but were but a summary of the book by Hermann Muthesius entitled *"Kunstgewerbe und Architektur"* which was published in 1907 and which constituted the foundation of Deutscher Werkbund, an organisation gathering architects, designers of applied art and industrialists, which aimed at stimulating such a creative spirit in the artists and designers which would provide the industry with attractive patterns for mass production.

The representatives of modernism (such as Adolf Loos and Otto Wagner in Vienna, Peter Behrens in Berlin or Frank Lloyd Wright in the USA) called for using new technologies and materials, such as concrete, reinforced concrete, iron, cast-iron and steel. At the same time many modernists also promoted more natural materials, such as natural stone, bricks and glass.

One of the aspects of modernism is also fascination with automotive and transport. It was in that period when the idea of a car town was developed and the car was an attribute of modern times. This was followed by construction of transport structures and systems, which intensified in particular after the World War II. Expanding the areas devoted to transport at the expense of greenery and of the society resulted in criticism and protests.

Examples of the aesthetics of this period will be:

- two welded bridges of Stefan Bryla on the Sludwia River in Poland,
- Maillart[50] bridges (Fig. 1.3.1.),
- and the bridges listed in subsections above

Adolf Loos died on 23 August 1933 in Vienna. In spite of many opponents, his ideas have become part of the essential principles of Bauhaus[51] and are the key element defining modernism. The theories and ideology of Loos appeared over 100 years ago yet until present they have both their followers and opponents. Many of these theories are applicable even today: the call for being guided by genuine needs instead of superficial aspirations, the call for exposing nature, materials and technology, or the call for economic and purposeful attitude to architecture and to the art as such, in particular in the times of crisis.

view on the role of urban design context.

[49] Tarnowski J., *Aesthetic transformations of architecture and town planning of the twentieth century*, „Aesthetics and Criticism", No. 2(3)2002.

50 Robert Maillart (1872–1940) – Swiss bridge engineer and architect.

[51] Bauhaus – the university of arts and crafts founded in Weimar as a result of the merger of the Academy of Fine Arts and the School of Applied Arts in 1919; later in 1925, Acting in Dessau (today Dessau) and 1932–1933 in Berlin. It was founded by Walter Gropius.

Figure 1.3.1. Maillart Bridge on the Salgina (*by ALT*)

## 1.4. Psychological and sociological bases of aesthetics *(ALT)*

There is not a single thing which someone somewhere has not regarded as beautiful nor anything whose beauty has not been denied [Tatarkiewicz, 1985]. Depending on whether road structures are beautiful or not for a given person, this person adopts certain aesthetic attitude towards them. The aesthetic attitude is also inseparable from the aesthetic experience. What we see inspires feelings in us. Many aesthetics have defined the subject of their studies not as beauty but as an ethical stance and ethical experience. They claimed that aesthetics may be regarded as science only if it is of psychological nature. The scope of the term "aesthetic experience" is different than that of terms "experience of beauty" and "experiencing the art". Each of the three great concepts of aesthetics – beauty, art and aesthetic experience – covers a slightly different range. According to the ancient Greeks, the organs perceiving beauty were eyes which see the symmetry and ears which hear the harmony, therefore perception of beauty consisted in focusing one sense. This first view of the aesthetic experience, which identifies them with the viewer's (and listener's) experience, was presented in a mature way by Aristotle in Greece. The father of the theory of aesthetic experience, seen from a slightly different perspective, was Plato. He acknowledged that the soul has the ability to perceive beauty and was convinced that the human mind has the ability to have aesthetic experiences. Plotinus[52] went one step further stating that only a person with inner beauty will see beauty in the world, therefore perception of beauty was conditional upon moral qualifications.

[52] Plotinus (gr. Πλωτῖνος Plotinos, (204–269) – ancient philosopher, creator of the philosophical system known as Neo-Platonism..

In Middle Ages Thomas Aquinas[53] in his work "*Summa theologiae*" developed the Aristotelian theory of aesthetic experiences but he distinguished the aesthetic experience from the biologically conditioned one. The former characterised only human beings and not animals. An intermediary between the Antique and the scholasticism was Boethius. He claimed, as did neo-Platonians, that in order to grasp beauty a person must have inner beauty. Medieval writers were trying to find in man this particular ability (the soul) which allows him to perceive beauty. In the theories of the Renaissance in turn there was a view that in order to experience beauty not only beauty of the object itself is needed, we also need this special ability the human mind is equipped with, i.e. we need the appropriate attitude, active or passive, of the person. In accordance with the first view, one must have the idea of beauty in his own mind in order to see beauty in things. In accordance with the second view, the beauty recipient needs only "*lentezza d'animo*" – submission to the soul.

A different position was presented in late Baroque where in "*Ragion poetica*" Gian Vincenzo Gravina[54] claimed that experiences of beauty and the art are a kind of ecstasy called *delirio*. The arrival of the Enlightenment led to the reflection on the aim of the aesthetic experience. In 1719 Jean-Baptiste Dubos[55] presented his theory of this claiming in *Réflexions critiques sur la poésie et sur la peinture* that the art and the aesthetic experience are a result of the mind's attempt to avoid boredom.

The 18$^{th}$ century was the time when innumerable treatises on aesthetic experiences were created. In England Locke replaced the analysis of being with the analysis of the mind while Shaftesbury regarded the issue of feelings and values as more important than the cognitive aspect of aesthetics. This is when the so-called "*sense of beauty*" emerged as a particular ability of the mind – sense of beauty, the notion of taste.

Diderot[56] believed that not everyone has the sense of beauty; actually, it is quite rare. Psychological analysis of the experience of beauty was practised intensively in England for the entire century and this is where associationism in aesthetics was established (subjectivity versus objectivity of aesthetic experiences), started earlier by the French Cl. Perrault[57].

In Germany Alexander Baumgarten[58] argued that aesthetic experience is merely "respresentatio sensitive", only sensual cognition but of a lower category, vague. The philosopher who made a synthesis of the German and English concepts was Immanuel Kant[59] in his "*Critique of the Power of Judgment*" (1790).

According to Kant, aesthetic experience which is not a cognitive act is something more than a mere experience of pleasure. Aesthetic experience is marked by the following: dis-

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[53] Thomas Aquinas (1225–1274) – scholastic philosopher, theologian and member of the Dominican order. One of the doctors of the Church, contemplata aliis tradere.

[54] Gian Vincenzo Gravina (1664–1718) – lawyer, legal historian critic and author of tragedies.

[55] Jean-Baptiste Dubos (1670–) – French historian, esthetician, diplomat and man of the Church.

[56] Denis Diderot (1713–1784) – French writer, encyclopedist of the Enlightenment period.

[57] Claude Perrault (1613–1688) – French physician and baroque architect..

[58] Alexander Gottlieb Baumgarten (1714–1762) – German philosopher from the school of Leibniz creator of the term aesthetics, the proper creator of aesthetics as an independent branch of philosophy.

[59] Immanuel Kant (1724 + 1804) – German philosopher of the Enlightenment, a professor of logic and metaphysics at the University of Königsberg. Developer of critical philosophy.

interestedness, non-conceptuality, formality, involvement of the whole mind, necessity (but a subjective one), universality (but without rules).

An easier theory of aesthetic experience was presented by Arthur Schopenhauer[60] in 1818 in his "*The World as Will and Representation*". He reduced aesthetic experience to contemplation experienced by everyone who takes the position of a "viewer", stops thinking abstractly and puts all the effort of his mind into observing a thing. The term "aesthetic stance" emerged.

In the second half of the 19th century common features of aesthetic experiences were discovered and there were efforts to include the aesthetics understood this way in the general theory using psychological method. The leading psychologists, aesthetics and philosophers of the 19th and 20th centuries believed that aesthetic experience is a unique experience, not comparable to others. This view was in conflict with the attempts to analyse aesthetic experiences. Finally, the most important theories of the 19th and 20th centuries may be formulated based on [Lagoda G. and M., 2014]:

- "sui generis" – the specific experience, not similar to others (representatives: W. Wundt, G.T. Fechner, J. Cohn);
- hedonic theory – the aesthetic experience has a as much value, as much pleasure it gives (G. Santayana, R. Müller-Freienfels);
- cognitive theories – aesthetic experience becomes a kind of knowledge, by analyzing the activities of the senses, brain and mind (B. Croce, K. Fiedler);
- illusionism – in contrary to the cognitive theories, aesthetic experience is a conscious illusion (C.G. Lange), feelings enclosed in illusion and virtual (E.V. Hartmann, M. Geiger), judgements and performances are virtual and fictional (A. Meinong, L. Balustein), aesthetic experience is a kind of a game (I. Kant, F. Schiller, Ch. Darwin, H. Spencer, K. Groos);
- theory of active nature of aesthetic experience, which is the theory of empathy (Th. Lipps, F.Th. Visher, H. Lotze, G.Th. Fechner, J. Volket);
- theory of contemplation – in contrary to the empathy theories, in aesthetic experience the pleasure is gained from objects watched, by seizing them and soaking their beauty (A. Schopenhauer, J.J. Rousseau, O. Külpe, C.J. Ducasse);
- theory of ecstasy – the aesthetic experience arrives when intellectual root is abandoned (E. Abramowski, P. Valey, E. Selincourt, H. Bremond).

The contemporary art is shaped rather by pluralist alternative theories which promise reaching an agreement between opposing views. The author of one of such theories was Ingarden[61] and it was propagated by him in particular in the book "*Experience, Work, Value*". Other contemporary pluralist concept of aesthetic experience appeared in the book "*Concentration and Dream*" by Tatarkiewicz. According to these theories, contemplation is in the end nothing but concentration on the thing which is to inspire aesthetic experience. What emotionalist theories see in this experience resembles what is commonly referred to as a dream.

[60] Arthur Schopenhauer (1788–1860) – German philosopher, representative of the.

[61] Roman Witold Ingarden (1893–1970) – Polish philosopher.

The psychological interpretation of aesthetics is somewhat dual. On the one hand, the artist in his creations expresses in an ideal way what he perceives, experiences and feels, achieving vital insight into the reality [Szuman, 1969], but on the other, a work awakens feelings in the recipient and the recipient adopts an aesthetic attitude towards the work. The results of psychological studies are indispensable to aesthetics, and more precisely to the theory of aesthetic experience [Golaszewska, 1985].

The creative process of the art, the circumstances in which it takes place, which in the end is decisive to the success of the artist, architect and engineer are the elements which are of interest to the aesthetics. Nevertheless, the art, regardless of whether it is an action of an individual or of a group, remains a component of social and cultural life and is often related to religion, politics or economy. This is where the sociological aspect of aesthetics can be seen. The history of aesthetic experience described above had a historical and social background. The socio-political situation of a given period had an impact on the development and the direction of such development in aesthetics.

The relations between the art and the social life, the impact of the society on the art and of the art on the social life are elements examined from the sociological perspective of aesthetics. People with their desires and needs create art, the art is perceived by people and the people shape those who deal with the art in a creative way. The art is by its nature social, such as societies are inherently co-shaped by the products of the art [Golka, 2008]. The art performs social functions: it models values and social ties.

## 1.5. A picture is worth a thousand words *(ALT)*

A picture is worth a thousand words – this is undoubtedly true. According to the psychologists, the messages communicated through lively, plastic calls and arguments in the form of images are more effective, mainly because they attract and keep the recipient's attention better and this way make the communicated information more precise and personal, plus they are easy to remember. This might be related to the primeval human instinct which has been coded in our genes for thousands of years. In the middle of the 4$^{th}$ century BC man, probably because he was striving to communicate his ideas better and to have the ability to communicate his thoughts to another human being, created pictographic writing, called picture writing. Schematic symbols of persons, animals and activities were used to present the elements of the reality surrounding people, to describe important events and rituals, to worship the first gods. Currently, in the times of technologically advanced civilizations we still see pictorial communication every day. Etiquettes, labels, various designations, pictures, albums, theatre, cinema, television, advertisement, infographics, Facebook, Instagram, emoticons: we see communication through pictures literally in every sphere of life.

Examples of picture communication in road structures are road signs, road traffic safety devices or vehicles marking used in transport. A designer of roads or of engineering structures prior to the beginning of the design phase has a certain idea of the object he is going to design. The easiest and the most direct way of realising a thought is to visualize it in the form of a picture as if a given object was really in front of our eyes. Our sight recognizes only what exists in the visible world. The mind works in a similar way, only that it also penetrates invisible areas. Every vision shapes in our imagination the product of our imaginings. The idea and the thought exist, and the next stage is to make them become realistic in the visible world. In the process of designing road structures the transfer of an idea to the visible world is carried out by way of a technical drawing, i.e. 2D, 3D and 4D visualizations. Designing roads and bridges is to a large extent based on communicating images. Multidimensional technical drawings and visualisations are currently effective methods of the design process. They support coordination of the spatial course of road structures as well as their harmonization with the surroundings.

Figure 1.5.1. Incredible footbridge in Turkey with an elevator for disabled (*by ALT)*


Figure 1.5.2. CaixaForum Art Gallery, Madrid, Spain, 2007[62]

[62] http://www.bryla.pl/bryla/56,85298,10626228,galeria-sztuki-caixaforum-madryt-hiszpania-2007-proj-herzog,,2.html

Figure 1.5.3. Surreal, strong bridge from the roots of wood; "construction" from 15 to 20 years, the older the stronger; does not require refurbishment; living bridge in Meghalya, India; source: [63]

Figure 1.5.4. Visualization Frenchmen Philippe Rizzotti, Vermet Tanguy, Manal Rachdi Samuel Nageotte revitalisation of the existing overpass over the road A3 Highway del Sole in Calabria, Italy; source: [64]

Chapter 5 contains a detailed description of visualisation types and the issues related to the design of road structures using visualisation.

[63] http://www.bbc.com/travel/story/20150218-indias-amazing-living-root-bridges

[64] www.newitalianblood.com/solarparksouth/projects/494-1.html; 02.12.2013

## 1.6. Harmony implies road safety *(ALT)*

Harmony (Greek: Ἁρμονία Harmonía, Latin: Concordia) is Greek personification of order and symmetry and in the history of aesthetics also: order, concord, unity, relation, communication. The ancient people linked harmony, order and symmetry with beauty. From the dawn of history aesthetics and beauty were inseparably intertwined with mathematical sciences and some of their aspects have their roots in such sciences. Archetypal nature of beauty of mathematical beings is visible in pre-Socrates aesthetics and the initial notion of *arche,* or the Pythagorean number are decisive for the future concepts of harmony and rationality (see the chapter History of Beauty). Pythagorean and Platonic concepts where the essence of beauty is defined as measurable, proportional set of elements which constitute a whole or Leibniz's conception of the order established by God which makes monads work in an orderly manner enabled harmony to present relevance and connection between the content of the human mind and the reality. Commensurateness, harmony, proportionality, symmetry, Euclidean geometry and arithmetic, all seen as beauty determinants have therefore defined the beauty canons in the Western tradition of the following ages. For many types of art and other forms of expressing beauty proportionality and symmetry may be interpreted directly, as quantity relations expressed in the language of mathematics.

These concepts from the start have been, and still are, present in the design and building of road structures. From the beginning there have been attempts to achieve harmony in construction of roads and bridges, sensing in a way, and later proving empirically, that this has a tangible impact not only on the aesthetic perception but also on the safety of travel.

In ancient times roads were set out without deviations directly to the destination, in line with the principle of harmony. Level differences were evened out by mastering the technique of building bridges, culverts and underbridges. Departure from the rule of straight route was allowed only for military or safety purposes (e.g. due to the risk of landslides). In such cases differences of elevations and slopes in the longitudinal profile were evened out by the construction of turns and serpentines. Alpine roads were quite steep but the elevation differences along the road did not exceed 15%. For example, there were initially three, later nine, and now twenty-two serpentines leading up to the Maloja Pass (1817 m), while the road through the Great St Bernard Pass along a distance of 27 km spanned the grade from 598 m (Aosta) to 2472 m (the pass). Roman roads for vehicles in the mountains had ruts with a pitch of 1.20 – 1.25 m in order to protect carts against avalanches. Handrails were also used to protect travelers from falling from the cliff, as well as retaining walls, protecting roads on slopes against sliding due to snow melt. Such retaining walls supported the Via Appia (43 meters high, near Aricia) and Via Flaminia (near the present day Urbino). Some Roman roads also ran in trenches (Via Flamina near Petra Pertusa) and tunnels (e.g. Via Appia near Terracino – the tunnel was 36 m deep and 4.44 m wide). The Romans also used road embankments reinforced by buttresses made of stone covered with turf (which additionally bound the stones together) and deck bridges for roads to cross swamps and wetlands. Deck bridges were made of wood by placing 3-meter long wooden logs on piles densely driven into the bottom, and then covered by compacted earth, gravel or stone slabs. These wooden bridges were the first underbridges in the history of road construction. For example Via Appia ran through the Pontine Marsh along a 28 km long dike, which was 3–4 m high and 20–23 m wide. After some time the embankments became widespread as the body of the road and Roman roads were elevated above the ground level.

From the very beginning there have been attempts to achieve the effect of harmony and balanced composition in the construction of road structures. This harmony is currently visible in striving for sustainable development (for more information on sustainable development please refer to "Environmental protection in road strucrtures"). Now it is not possible to design a road or a bridge without an interdisciplinary team composed of road engineers, bridge engineers, as well as architects, town planning specialists, ecologists or natural scientists. The contemporary design methods draw on the scientific base related to restitution, spatial analysis [Zakowska, 2014], transport psychology and eco-engineering.

In order to design road structures in accordance with the principle of harmony an engineer should have knowledge of the basic principles of perspective.

Perspective is the most frequently used and the most natural way for man to imitate space on a flat surface. There are a few types of perspective: linear (convergent, geometric), colour (painterly), overlapping, aerial, reversed, curvilinear (correct). The perspective can also be divided into single-point perspective, multi-point (6 points maximum) perspective, frog's perspective and bird's-eye view perspective.

Linear perspective, also called geometric or one-point perspective, is a way of representing depth using middle projection. It is a special way of depicting 3D space on flat surface which resembles space as seen by the human eye. This technique allows for presenting flat surface in such a way that it seems deep.

Linear perspective was already known in the ancient times. In Middle Ages paintings were mainly two-dimensional. The attempts to present objects in three dimensions wree made again in the 14$^{th}$ century (frescos of Giotto di Bondone, works of some of the painters contemporary with him). The first person who defined principles of linear perspective in the 15$^{th}$ century was the architect from Florence, Leon Battista Alberti. The basic principle is apparent reduction of the object size as it goes further away from the viewer and apparent convergence towards the horizon of all the lines going from the viewer's eyes to the object. It is assumed that the first person who prepared a fully correct linear perspective was F. Brunelleschi. In Baroque complex perspective was widely used with numerous foreshortenings (trompe l'oeil paintings). In the 18$^{th}$ century optical instruments started being used in order to achieve perfect perspective (Fig. 1.6.1.).

The essence of perspective is the projection of all the points of the space on a plane or other surface, with respect to a point called the center of perspective. This presentation creates an image in which (in addition to some specific situation) true dimensions and angles in space are not preserved. The image is deformed – characteristic of this is that the elements presented in the image "decrease" and they move away from the viewpoint. Parallel lines become convergent in the perspective and they meet at a theoretical point.

Figure 1.6.1. Linear perspective on an expressway S17, Poland (*by ALT)*

Creating a path that forms a harmonious whole with the surrounding landscape and includes in the well-ordered relations all the conditions as well as functional, socio-economic, environmental, cultural, composition and aesthetic requirements is the task of the 21st century designer of road structures.

## 2. Chosen aesthetics tools *(SLK)*

*Canon* (an aesthetic one, for instance) refers to a set of written or unwritten principles and rules that constitute the basis of a classification from the lowest to highest artistic or aesthetic value.It occurs in many areas, in particular aesthetics, ethics, architecture or art. Canons shift, usually with evolutionary and revolutionary social changes.

In art and architecture the following canons can be identified. The canon of the ancient Egypt's art dealt with art, politics and religion. A force modular system built on a grid of squares. A standing figure was divided into 19 parts, and a sitting one into 15. The individual parts of the body corresponded to a fixed number of squares. Among the Greek canons the one formulated by Polyclitus, 5th century B.C., comes first. He introduced a division into modules. The basic module was the width of a finger. The size of the head was supposed to be 1/8 of the height of a man, a hand – 1/10.According to the Lysippos's canon, the height of a man had 9 modules, including head which accounted for 1/9 of the whole.

The valid canon during the transitional period between the Greek and Roman worlds was defined by Vitruvius in his *The Ten Books on Architecture*, 1st century B.C. During the Renaissance, Leonardo da Vinci's canon introduced his idea of proportions – the Renaissance Canon. The system assumes the proportions of human figure as based on the Vitruvius books. A man is typed simultaneously in a square and a circle for which the common point are the bottoms of the square and the circle. Equally strong influence on artistic concepts had Dürer's man, and especially the study of proportions of the female body.

### 2.1. Harmony v. dominant feature

***Harmonious can mean non-contradictory.***

Harmony, in its essence, primarily regards music. Because music is everything, if it is, also harmony may refer to everything, including civil engineering. The well-known concept of the schedule, in some languages, may resemble in writing and in speech, the word *harmony* (*harmonogram*, Polish). In Viet Nam[65], Hanoi, *harmony* means the equilibrium between bad and good, sweet and bitter, success and failure, privilege and responsibility, and so forth. This approach is universal. Adults have responsibilities towards children, and children must curb their vitality. Dinner should be compose with this dishes sharper in flavor and mild, in order to achieve a balance sensations. After hard work there is time for rest. Only one social activity has no balancing option. It is war.

Human mental harmony can result from *the positive disintegration*. This concept was introduced into the scientific lexicon by Kazimierz Dąbrowski[66], [Dąbrowski 1964; Dąbrowski, 1966].

[65] The concept is an extension of the Confucianism idea, explained by prof. Nguyen Hoo Viem, previously the lector of Theory of Elasticity at Lublin University of Technology.

[66] Kazimierz Dąbrowski (1902-1980), Polish psychiatrist.

In short, according to *Theory of Positive Disintegration*-TPD mental life is a process where a disintegration lower level is possible, but at the same time – a reintegration on higher level. Dąbrowski called such psychological processes TPD. In this perspective, occurs a harmony limit which has a place only when there TPD appear. Dąbrowski provided a control methodology with regard to mental disintegration processes, so that a viable option of reintegration at a higher level is indicated.

This approach means that harmony offers the opportunity to know/try everything and can be expressed in the words of the maxim *Homo sum, humani nihil a me alienum puto*[67].Harmony in architecture means that all parts of the visual relate to and complement each other[68]. Modern public facilities, including roads and bridges, owe their beauty to the idea of intermingling and combining architecture and nature.

## 2.2. Dominant feature

Another essential element of design is a dominant feature, which can be constituted by a strong single element, but also as a proceeding guiding line which can achieve the climax point – the dominant feature. In the case of bridges this dominant feature occurs when the cable bridges with pylons are considered. The vertical columns divide the landscape into sub-fields or in the case of cable stayed bridges such a dominant feature is incorporated into the web of straight lines of the cable system.

A whole bridge can be the dominant feature of a landscape but on the other hand it can also be a quasi-dominant one. Actually, a bridge becomes an element of natural or urban surroundings to a certain degree. This domination is only visible when the elements of the surroundings have less distinct shape, colour and height.

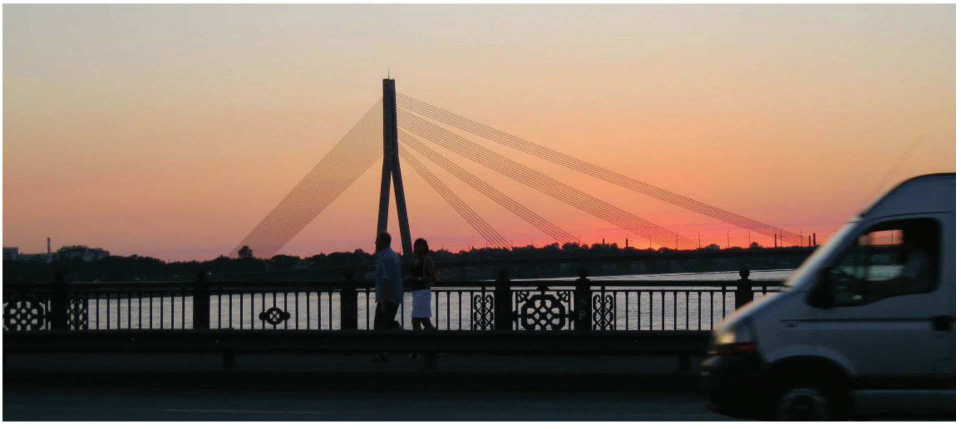


Figure 2.2.1. Cable stayed bridge at sunset, Riga (*by dr. Marta Słowik*)

In the above photo, the pylon is an unquestioned dominant feature of the image and simultaneously it contributed to the overall harmony.

[67] Publius Terentius Afer (195-159 BC), Roman comedy writter, I am a man, and all that is human is alien to me.

[68] http://www.educ.kent.edu/community/VLO/Design/principles/harmony/index.html; [26.11.2015].

## 2.3. Proportion

Aesthetics offers many interesting and helpful tools by means of which one can explore image aesthetics. Where the tools are of a static nature, which usually applies to painting, they are not useful with regard to spatial images which are bit like a film clip.

To start, consider the idea of the golden ratio which is also known as the golden mean. This issue have fascinated many people over the centuries. Starting from antiquity until the present day people have sought methods of the image composition which would have at least two characteristics:

- a possibility of indicateing high aesthetic conditions, which consequently disqualifies poor aesthetics, and
- geometric measure e.g. proportion/ratio, easily supported by mathematical justification, such that, should be clear and applicable in art, architecture and in other domains.

This is precisely the case of universal aesthetic image classification by means of the golden mean division. In the one-dimensional case it is the internal (external) division of a line segment. It has been accepted that, aesthetically, the best measure of the distribution of the horizontal section is when following geometric proportions are kept, Fig. 2.3.1,

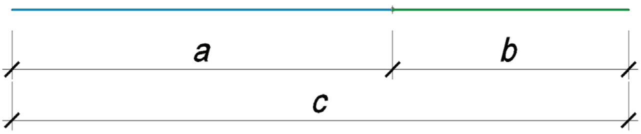



Figure 2.3.1. One-dimensional *Golden Mean* case

$$\frac{a}{b} = \frac{c = a + b}{a} = \varphi \tag{1}$$

where $\varphi$ is the *golden number.*

Equation (1) leads to the algebraic square relation of the harmonic mean

$$\frac{1}{b + c} = \frac{1}{a} + \frac{1}{b} \tag{2}$$

or leads to the expression of a particular case of the Egiptian triangle (sides: 3, 4, 5) or if someone wants something more, it leads to the special case of the Pythagorean[69] theorem, see Fig. 2.3.2.,

$$c^2 = a^2 + b^2 \tag{3}$$

where $a = 1$, $b = \sqrt{\varphi}$ and $c = \varphi$.

[69] Pythagoras (~572-497 BC), Greek geometer, philosopher

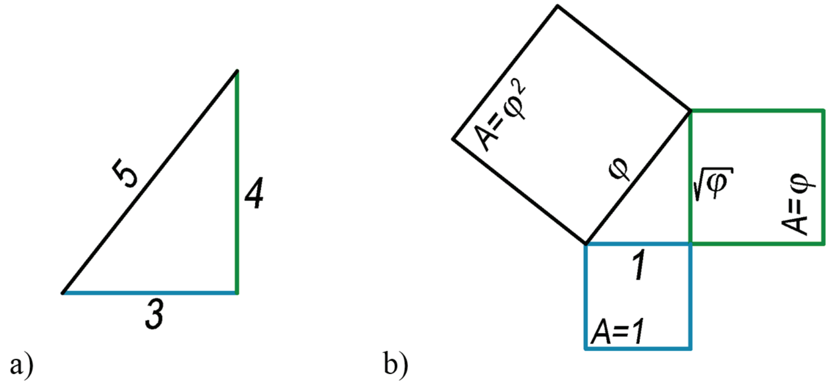



Figure 2.3.2. *Golden Mean* expressed by plane geometry examples a) Pythagorean beauty triangle b) Pythagorean Theorem in the case of Kepler[70] triangle

Having the square relation it is possible to calculate the value of the *golden number* which is equal to

$$\varphi = \frac{1+\sqrt{5}}{2} \approx 1{,}6180339887\ \ldots \quad (4)$$

The value of the golden number was given for the first time by Maestlin[71].

The *Golden number* can be obtained by analysing the Fibonacci[72] sequences. The basic Fibonacci sequence (1202) is a sequence of natural numbers recursively defined as follows: the first word is 0, the second is 1, and every subsequent one is the sum of the previous two:

| $F_0$ | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ | $F_7$ | $F_8$ | $F_9$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 2 | 3 | 5 | 8 | 13 | 21 | 34 |

(5)

or formally as

$$F_n = \begin{Bmatrix} o & \leftrightarrow & n=0 \\ 1 & \leftrightarrow & n=1 \\ F_{n-1}+F_{n-2} & & \end{Bmatrix} . \quad (6)$$

Using the expression proposed by Binet[73] one can calculate any element of the Fibonacci sequence by means of the *golden number*s following

[70] Johannes Kepler (1571-1630), German mathematician and astronomer

[71] Michael Maestlin or also Möstlin (1550-1631), German mathematician and astronomer. Copernicus' heliocentrism propagator.

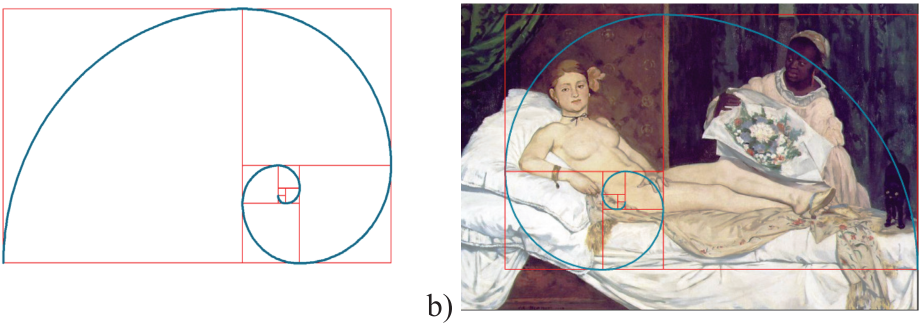
[72] Leonardo Fibonacci (1175–1250), Italian mathematician known as Leonardo Pisano.

[73] Jacques Philippe Marie Binet (1786-1856), French mathematician, physicist and astronomer. He dealt with number theory and algebra matrix, is the author of an explicit formula for the nth term of the Fibonacci sequence.

$$F_n = \frac{\varphi^n - (-\varphi)^{-n}}{\sqrt{5}} \tag{7}$$

And also at limit we have

$$n \to \infty \;\; then \;\; \lim \frac{F_{n+a}}{F_n} = \varphi^a . \tag{8}$$



a) b)

Figure 2.3.3. Fibonacci *golden spiral* a) construction b) application in Manet's *Olympia*[74]

The Fibonacci numbers can be used to create the plain aesthetical graph known as *the golden spiral*, see Fig. 2.3.3.a. Using the squares whose sides are equal to the following numbers of the Fibonacci sequence, by drawing the spiral with the quadrants of adequately sequential set of circles (similar to a logarithmic spiral). The founded curve includes the distances included in the golden number proportion. It is used to evaluate the aesthetics of the composition of a painting. The *spiral* has been used in many cases, see Fig. 2.3.3.b and Fig. 2.3.4.a, for examples.

The modularity of the human body, which was introduced by Polyclitus, is still a living idea[75]. One of the leading architects of the twentieth century, Le Corbusier, developed his own system of the modules of a man called *Modulor* Fig. 2.3.3.b. While Polyclitus's man is primarily a statue, for Le Corbusier the man is the entity of architecture. Man – athlete, worker, teacher, they all live in the world created for them by means of architecture.

[74] The drawing was plotted on the basis of: https://www.pinterest.com/pin/247627679485725230/

[75] Le Corbusier, as above.

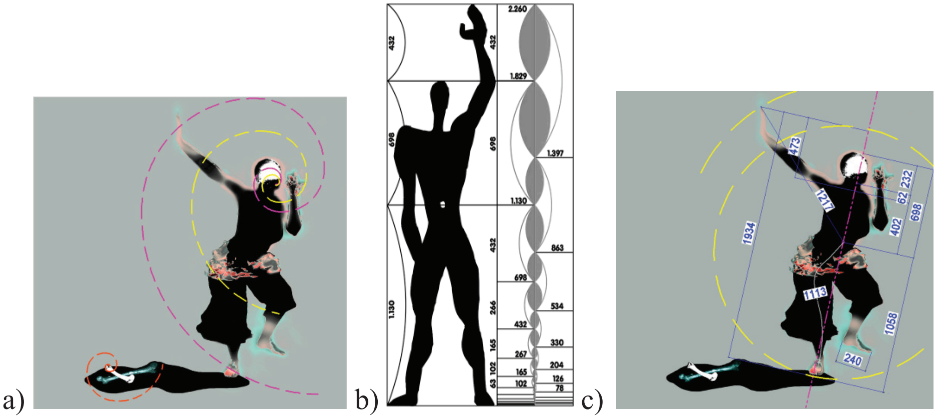



Figure 2.3.4. *Danceuse grise*[76] a) beauty and proportionality analysis by golden spirals b) Le Corbusier's Modulor c) Modulor in *Danceuse grise*

The correctness of the modules of the human body must be verified by artists' works. In Figure 2.3.4.c Le Corbusier's measure is applied to a girl dancing the *Guineě Fare* dance. Although Modulor in its many presentations is static, here inclined, and corresponds to the dimensions of dancing vibrant figure. The analysed image has many connotations. Here, the focus was on the proportions only.

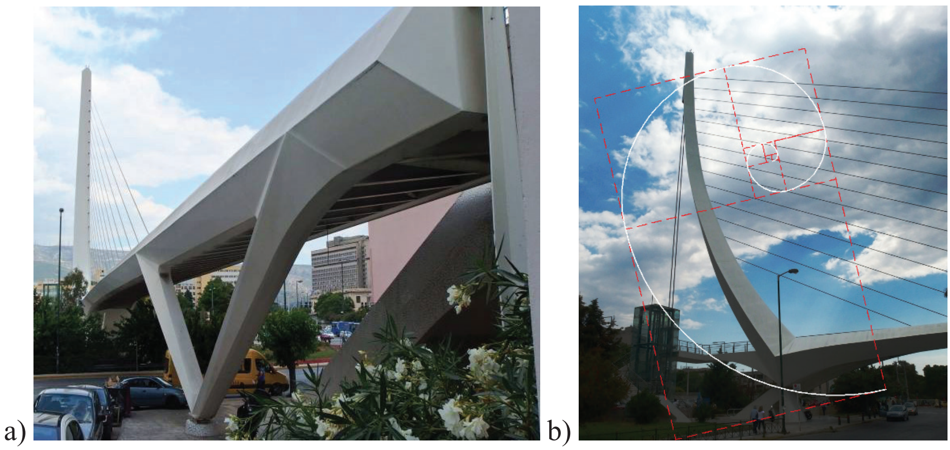



Figure 2.3.5. Katehaki pedestrian bridge – Athens, by S. Calatrava, 2004 a) a bridge view b) the golden spiral on the bridge image

In terms of perception a bridge is a more difficult object than a known painting hanging in an art gallery. It is best illustrated if one treats the bridge as a movie. It will be other scenario for a pedestrian, cyclist or a car driver. It could be a real movie made by movie camera. Despite the fact that the film is a younger art than photography, moving images are often the subject of an aesthetic analysis. Probably, because a photograph

[76] by Kamila Rosinska, private gallery Natalin 7, near Krasnik, Poland

is a more focused image, the photo is taken with a more thoughtful recognition of the best and it is archived in a static form. Besides, it is not trivial that a photograph may be repeated from different perspectives many times.

Currently we shall repeat an attempt to assess the aesthetic by means of the golden spiral. For the planed experiment was selected one of the most beautiful bridges of Santiago Calatrava – the footbridge in the centre of Athens, Fig. 2.3.5.

The spiral can be treated directly in accordance with its definition. Therefore, one can search for the classification of the image by proportions used and its aesthetical values in the image composition. These values are created on the basis of the regularity occurrence. It is also possible to refer to the spiral generalization. A spiral of the same shape contains, in itself, a kind of a centre and its surroundings. Both concepts are relevant in the present case.

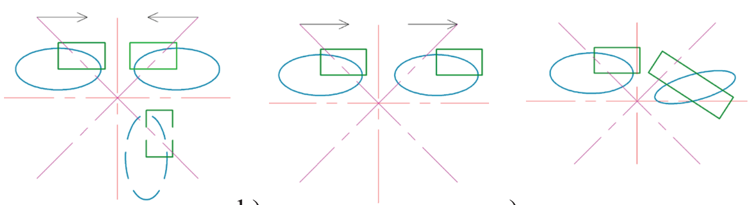
The most exciting place in the image of this bridge is the delicate parallel steel lines set. It is of course clear that they are indeed steel cables suspending the platform. However, the design and construction in the picture are not complete. For this reason, this incompleteness has an irritant optimistic beauty of the unknown.

Due to this, the spiral centre was located/beginning in that place. Paradoxically, a massive pylon does not arouse anxiety; quite the opposite – its bow and sail creates a sense of calm and grace which must have been known among the Mediterranean sailors.This certainty extends onto another deli supporting element, namely the thin bow tie which runs downwards. All elements are housed in a spiral.

It is a possible interpretation, but especially the art and aesthetics are very subjective, as it is truth, therefore everything can be written differently, just from the beginning. One thing is sure: the golden spiral is useless in the case of Mondrian, Kandinsky or Miro, but again – who knows?

## 2.4. Symmetries

This chapter discusses elementary problems of the plane symmetry. Symmetries include: symmetry, Fig. 2.4.1.a, a skew symmetry – anti-symmetry, Fig. 2.4.1.b, or finally the opposite of these two terms – asymmetry, Fig. 2.4.1.c. Symmetry and anti-symmetry belong to the group of isometric transformations. Isometry reveals the equality of characteristics independently of a chosen direction.

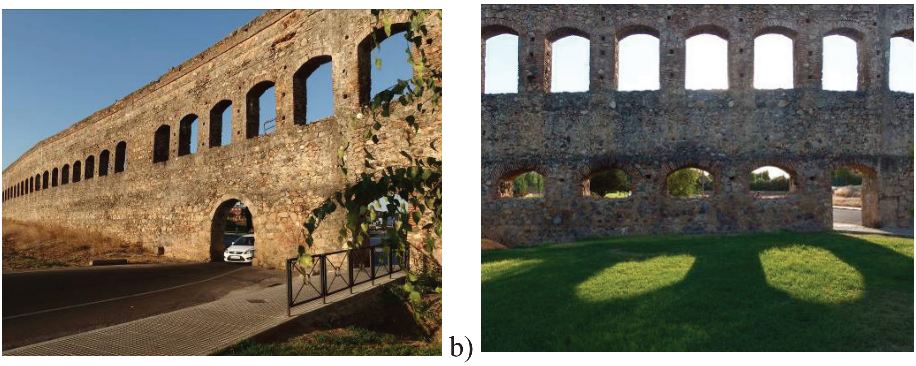


a) b) c)

Figure 2.4.1. Figure symmetries a) symmetry along vertical and skew axis b) symmetry along vertical axes c) asymmetry

When commenting on Fig. 2.4.1.a–b, it is worth mentioning that numbers (e.g. lengths) are qualitatively different than vectors (oriented sections), symmetries which in relation to figures look almost contradictory. This results from vector characteristics, however, the vector nature will not be discussed here. Figure symmetries are to be obtained by: shifts, orthogonal rotations or a mirror reflection.

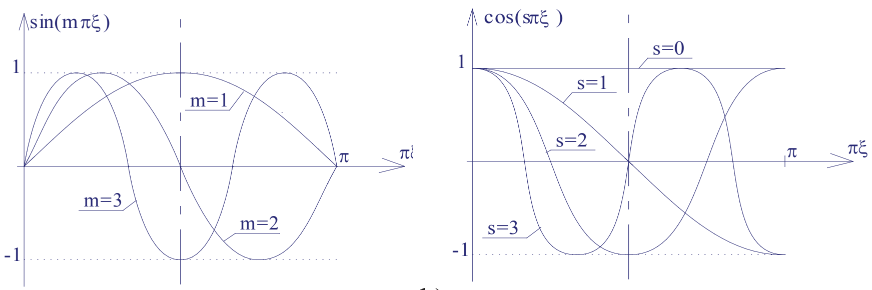
An axonometric drawing is an oblique graphical projection applied to obtain plain drawings of three-dimensional objects. It is very useful when one wants to show an existing bridge in its natural surroundings. It is not a perspective. Actually the majority of photos showing the side view and at the same time the longitudinal view, of a bridge are made, more or less, by means of an axonometric projection.



a) b)

Figure 2.4.2. Acueducto de San Lázaro, 1st century AD, Mérida, Spain a) the photo where the axonometric technique as well as perspective are visible b) front view – symmetry

The mathematical symmetry and anti-symmetry is best introduced by analysing sines and cosines graphs. Let us analyse the waveforms graphically in the case of the next several functions. We will use dimensionless coordinate $\xi \subset <0;1>$, see Fig. 2.4.3.




a) b)

Figure 2.4.3. Sines and cosines modes a) $\sin(m\pi\xi), m = 1,2,3$ b) a) $\cos(s\pi\xi), s = 0,1,2,3$ It is commonly known that

$$-\sin(\xi) = [\cos(\xi)]. \tag{9}$$

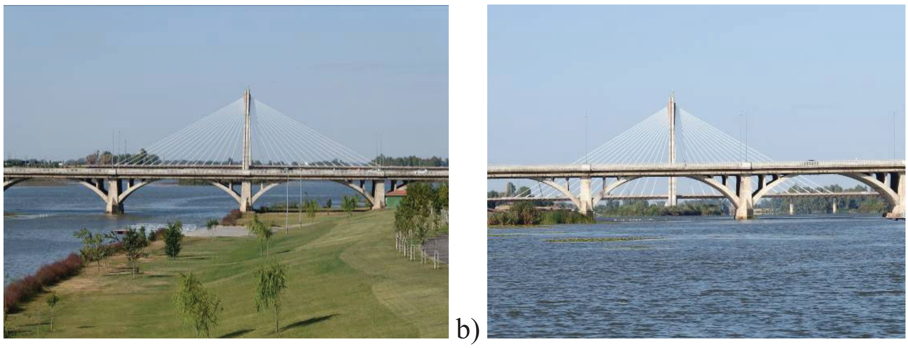
The set of $\sin(k\pi\xi)$ and $\cos(k\pi\xi)$ are used in Fourier's[77] series because they are a *complete set of functions*. However, some additional conditions have to be fulfilled, [Толстов, 1980].

Sine functions are known as anti-symmetric ones, but only on the domain is $< -\pi;\pi >$ for this instance cosines are symmetric. When analysed on the domain $< 0;\pi >$ according to the vertical line $\xi = \frac{1}{2}$ the sines/cosines display another nature. In the case of sines, the sines for odd indices are anti-symmetric and for even values of indices are symmetric. In the case of cosines we have a reverse situation. Additionally, the index $s = 0$ is assumed as even and its graph stands for a constant function $f = 1$.

Sadly, sine or cosine arches are not in use in bridge engineering.

## 2.5. Clarity of form in urban and country landscape

Watching a bridge is like a movie of one actor in similar but different expositions. The urban area creates funny images, see fig. 2.5.1. In Badajos, where the Guadiana River flows through the city and where 4 bridges were built, we can observe an overlapping of images of two bridges when walking on the third one.



a) b)

Figure 2.5.1. Badajos, the view from the Roman Bridge in the upstream direction a) overlapping of the pillar and the pylon b) the shift between the pillar and the pylon

The situation discussed in Fig. 2.5.1. can be classified as unstable. It is not a general case but happens time to time. A very strong dominant feature of the vertical pylon of a cable stayed bridge becomes fuzzy due to its changeable relative position.

The other experiment on stability is shown in Fig. 2.5.2 where the Guadiana River in Merida is crossed by 4 big bridges.

[77] Jean Baptiste Joseph Fourie (1768-1830), French mathematician; see Théorie analytique de la chaleur.

a)

b)

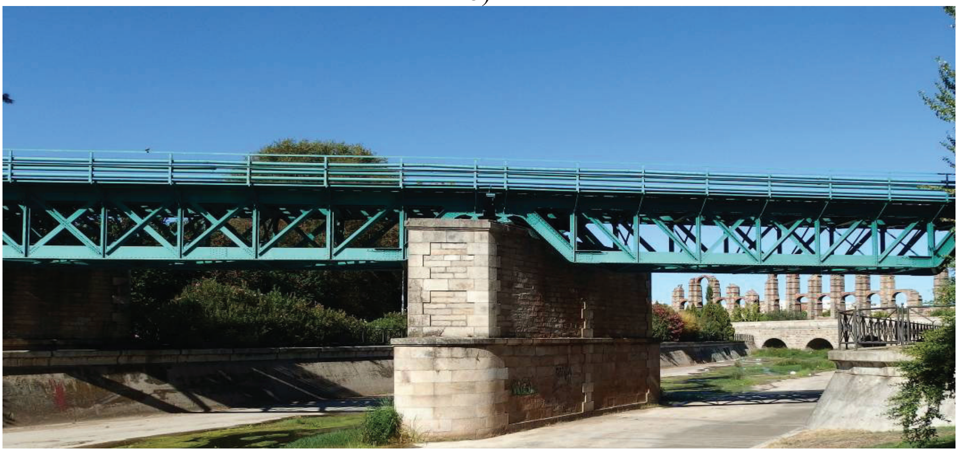


Figure 2.5.2. Merida bridges a) The Calatrava arch *over* the multiarch Roman Bridge[78] b) 3 in one plane – contemporary Rail Bridge, next is Puente de Albarregas, Roman Bridge[79] at the back there is Acquedotto Los Milagros

In Fig. 2.5.2. the chaos of too many bridges in one photo is observed. Also we can identify something like coexistence and this, by definition, is a case of harmony of different human activity effects with respect to bridges. However, keeping a proper distance is necessary, whatever it may mean.

This is the example of a modern cable stayed bridge which is a dominant feature and is placed in the natural landscape as its supplement that enhances the view. The very crude mountain and a rocky view is brightened by a heavy concrete bridge, Fig. 2.5.3.

[78] Overall length of 755 m with 62 spans.

[79] 4 granite ashlar arches, with two wider arches, which are the overflow channel of the aqueduct. It is parallel to Los Milagros aqueduct.

a)

b)

Figure 2.5.3. Gran Canaria, GC21 Road near to Teror a) side view of the bridge over a volcanic canyon b) cable system

This is a rare case when a heavy bridge structure enlivens the surroundings. It is a typical construction, which may be different every time. The adjustment of the shown bridge to another covers the foundation and service arrangement. In this case, the bridge has 2 lanes of vehicle traffic, no sidewalks for pedestrians. The viaduct was built in 2010, it's 261m long and 75m high.

Finally, an example of a dominant feature in a landscape. The Lusitania Bridge in Merida designed for vehicle drivers, pedestrians and cyclists is a monumental structure when looked at by an approaching entity. First of all, it is necessary to mention that the city buildings are not high and neither is the landscape which is slightly and mildly mutable due to the relatively wide river valley. The central, axial, lane is intended for people while the traffic runs on the bridge sides, see Fig. 2.5.4.


Fig 2.5.4. The dominant feature of Guadiana River Valley. Walking, step by step, by the Lusitania Bridge: a) entrance b) approach to a tower c) heavy, medieval-like gate d)–f) solar glare g) exit h) leaving the bridge

A walk along the bridge is a fascinating experience, even if one hurries to the bus or train stations, located on different sides of the bridge. It is not only a bridge it is also a spectacular dominant feature.

## 2.6. Graffiti

Graffiti is a challenge and practically nobody wants to face the problem. Graffiti is a branch of art of a rather underground nature.

Let us try to develop a definition of the graffiti art and graffiti artists. The real graffiti is a protest of young artists. In general, they are not accepted. They are not adapted to the hierarchical cultural and social situation.



b)


c)

d)

e)

f)

g)


h)

Figure 2.6.1. Graffiti a) an interesting coloured painting on Roana bridge b) Katehaki footbridge with graffiti) narrow pedestrian transition with graffiti scenes d) narrow transition pedestrian entrance in flat wall coloured in burnt sienna e) interesting graffiti on recently renovated RC historic bridge f) 7 km long wall painted in scenes of Viet Nam, Hanoi g)–h) *grey* bridges decorated with *grey graffiti* – harmony?

Nobody understands the artists and their protests. This art is an expression of lost but resilient teens. They are willing to fight. Spray paint is used. Generally, they are not educated in fine art, composition and art techniques. In many cases they are not educated at all. The subject of their paintings is not defined to the end. Action is what is the most important.

The above definition is a summary of numerous discussions with graffiti artists.

In the past, similar cases occurred repeatedly and they are known as rejected art. The most famous case was the *Salon de Refusés* in Paris in the $19^{th}$ century. The official summary of artistic activity took place during the exhibition called the Salon. Only academic works were eligible for the exhibition. The decisions of the jury over time were becoming more and more conservative and, consequently, new trends in art were ignored. At some point a large group of artists proposing a new approach to painting were officially rejected. In this moment the rejected art salon came to being – Salon de Refusés (1830).

This history does not repeat itself in the case of graffiti. Graffiti artists do not work for profit, therefore they are not forced to conform to any rules. Settling down means a departure from the principle of protest against the establishment. A part of them move to galleries, but it means their end. Nevertheless, new graffiti artists keep appearing.

Their art is a form of vandalism. To protect buildings against graffiti some considerable funds are spent. Also, washable coatings are produced.

Nevertheless, the protection against graffiti is only partially effective.

# 3. Aesthetical studies on roads and tunnels as well as bridges

## 3.1. Roads and road users *(SLK)*

The travel speed and the aesthetics of a road constitute a stream of life. Everywhere where a road comes there is a possibility of getting a job, developing a human relationship, relaxing, having a better life and brighter future. In this sense a road has a similar meaning to the bridge concept, i.e. connecting different people and enabling their actions. The sustainable development in road engineering means limiting air pollution during construction works and exploitation, especially those which are vehicle by-products, economy, safety and the protection of environment.

A road means also z system of pavements, signs, lights, safety facilities, bridges, animal transitions, crossroads, urban and country forest areas, services for travellers, especially for drivers, monitoring and probably a dozen of other elements.

Nowadays, it is thought that the primary relation is the one between the driver/traveller and the road adjusted to his/her skills. On the driver's side we can list his awareness of the traffic rules and law in general, physical state and readiness for flexible behaviour, education, resistance to traffic problems, calmness and even politeness. The road adjustment to the predefined model vehicle driver is simply its design. We can distinguish several basic elements of the design. Firstly, in the geometrical sense, it is a spatial system containing straight sections, horizontal and vertical curves, declines and nodes or crossroads. With a suitable handbook of road design we can implement the geometric phase fulfilling safety and comfort conditions for driver or travellers. The most difficult part of a new road design is to plan its route.

The driver of a car does not feel the environment. He/she has a momentary perception of the environmental harmony, colours, morphological variation, etc. On the other hand, the driver certainly sees and feels the interior of his/her car. He/she listens to the radio, watches the road which is a kind of an on-going show. Just like in the TV series the theme is the same, but new actors appear every now and then.

For the driver, the feeling of freedom is experienced in full when they and they only decide the driving speed. However, it is not always fully possible. For this reason the driver's primary function is to monitor limits of the vehicle speed to avoid punishment.

In such conditions a driver who is passing through a forest decelerates as there is a threat of the emergence of wild game on the road. A driver reacts similarly when driving in rural areas. Driving in the city is perceived differently as it is subject to a complex set of road signs. In the above-mentioned variety of factors, the impact of vehicle technical quality is relevant. Even if we assume that the car is driveable, we must keep in mind the differences in driving a car or a truck. The road visibility for the driver of a car directly following a bus is completely different than when driving behind a car.

For the driver the most stressful condition is waiting in a traffic jam. For example, a traffic jam at the exits and entrances onto highways intersecting near Venice. Every day, in the afternoon peak hours, around 4 p.m., thousands of cars are waiting to enter highways. It is caused by the system of gates, where toll is collected. Traffic jams on motorways are connected with traffic accidents. In such a case everything depends on the efficiency of the police and traffic services. the reduction of traffic jams in the centres of large cities is carried out by means of an entry ban of a large number of cars. Here we can give the examples of London or Rome where only buses, taxis and residents' vehicles are allowed to enter the city centre [Stokols D., et al., 1978; Wickens Ch., et al., 2013].

## 3.2. Vertical and horizontal road marking – clarity and relevant labelling *(SLK)*

Aesthetics on the road is very strongly associated with the traffic safety. The legibility of vertical and horizontal road signs conditions a swift and certain response of a vehicle driver. This applies as much to urban areas as to roads running through interesting country landscapes although these situations are completely different. They are linked by the requirement of the legibility of labels to ensure the safety of traffic participants.

In Fig. 3.2.1, signposting arrangements are presented according to urban and rural street/road.The centre of Hong Kong is a crowded area both with regard to the traffic and pedestrians. However, the safety is ensured through an efficient traffic light system, correct and unified marking and a widespread awareness of the need to obey traffic rules, Fig. 3.2.1.a–b, see also [VicRoads, 2014]. Eindhoven suburbs have eased the traffic intensity which is proportional to the number of inhabitants the requirements of local shops, offices, schools, etc. The segregation of pedestrian, cyclist and vehicle traffic is arranged by means of colour lanes and typical devices such as curbs, traffic lights, painted roadway lines, Fig. 3.2.1.c–d, see [EN 12966-1]. Local roads as well as expressways in Spain have simple, clear and extremely readable form constituted by horizontal markings and white line system painted on a pavement. The directional boards, frequently doubled, redirects to local and main places on the road. On other boards the speed limits are displayed, Fig. 3.2.1.e–f, see [Highway Guide, 2006].In the urban area, highways produce an unpleasant noise. For this reason, acoustic screens are used. An opaque acoustic wall may bring a sense of claustrophobia to car drivers, so any modification by colour or a *window* is friendly to road users, Fig. 3.2.1.g–h, see [Guidelines on Design, 2003].

Country roads are another type of the Polish road curiosities, Fig. 3.2.1.i–j. Despite constant changes for the better, rural roads are still of the lowest standard. Low pavement standards, bad maintenance result in substantial operating costs and numerous vehicle suspension damages. It is true that traffic on these roads is small. It can be estimated at tens to hundreds vehicles passing per day. However, bearing in mind that these roads are in rural areas, there is a large variety of vehicles. There are ordinary passenger cars, but also heavy agricultural machines. The are problems resulting unobvious responsability. These roads are often owned by individual persons or small communities.

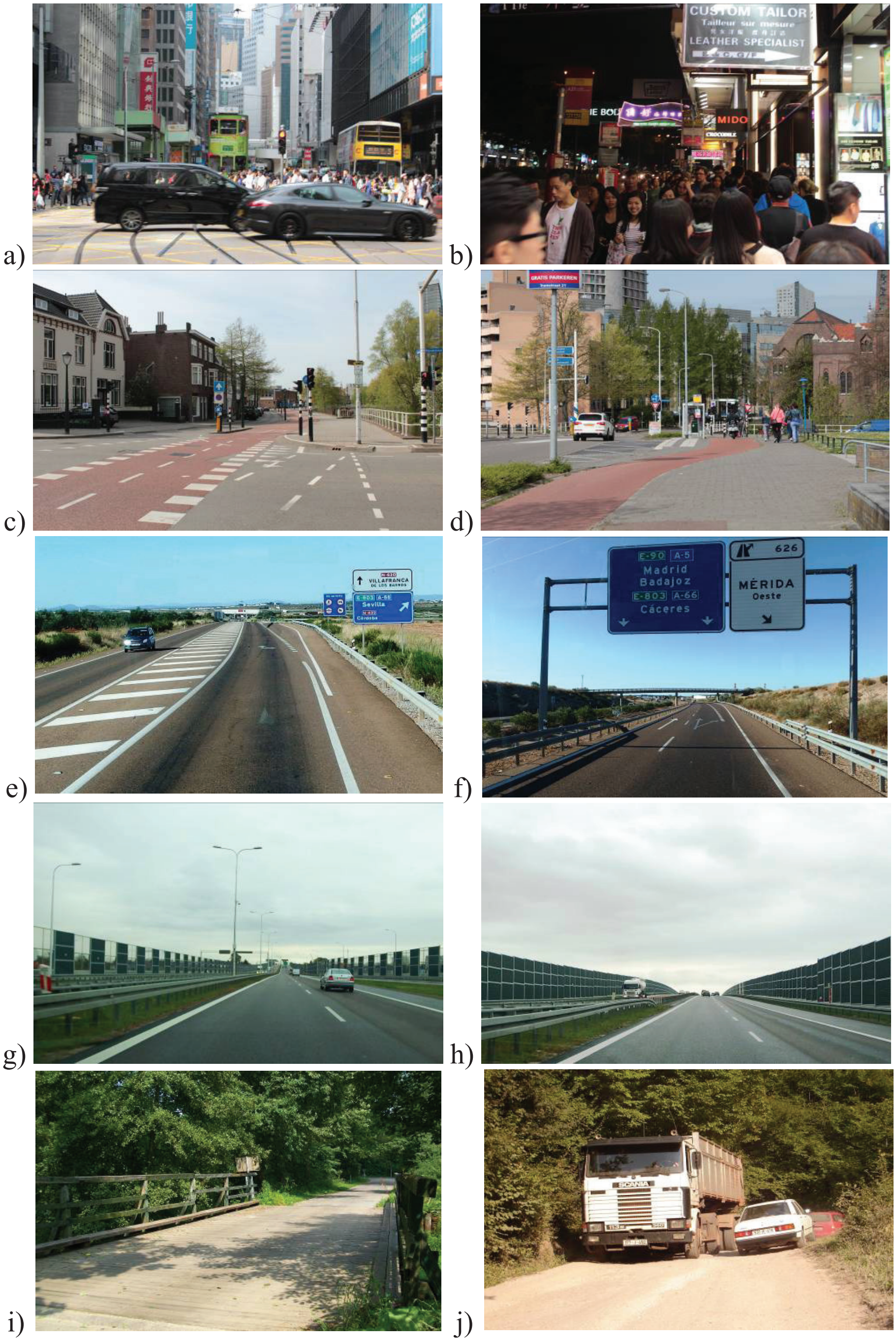



Figure 3.2.1. Road arrangement a–b) big city traffic (HK) c–d) vertical and horizontal markings on a street (NL) e–f) markings on the expressway (ES) g–h) noise screens on an expressway (PL) i–j) country roads (PL); (*a–d photos by Paulina Jaminska*)

In both cases, they are financially incapable to build a new road and maintain it properly. It appears that these issues require a longer time to be solved. The vernacularity of rural roads is very attractive for tourists but is not so romantic for everyday users [see: Practitioner's Guide, 2013]. The above overview sketchily presents a large variety of road issues, including safety, maintenance and road usefulness.

## 3.3. Bridge objects – types *(MJ)*

Traffic engineering structures play a very important role in shaping the space around. In the pictures below are shown different types of bridge structures. Bride object are designated to carry the road/rail traffic, however those object can also be nice, whatever it means. The photos below are trials to show the mentioned beauty and may be aesthetics, also.

Bridge's objects we called engineering structures, whose main task is to conduct various kinds of transportation through the obstacles, which can be:

- watercourses: rivers, lakes, ponds, canals, bays Marine,
- valleys, ravines, roads intersection, eg. With rail roads.

Bridge's objects can be divided because of the nature of obstacles:

- bridges (fig. 3.3.1),
- viaducts (fig. 3.3.2),
- footbridge (fig. 3.3.3),
- flyover (fig. 3.3.4).

Figure 3.3.1. Road bridge in Chongqing "Dragon Eco Bridge"[80]

[80] http://trendz.pl/trendy/futurystyczny-most-w-chongqing-dragon-eco-bridge

Figure 3.3.2. Road Viaduct in Mszczonów[81]

Figure 3.3.3. Footbridge in Krakow[82]

81 http://www.pomost.com.pl/projekty/wiadukt-na-drodze-nr-8-w-mszczonowie,50,0.html

82http://www.polskiekrajobrazy.pl/Galerie/604:Malopolska/39352:Krakowska_kladka_dla_pieszych_i_rowerzystow_na_Wisle_widziana_od_strony_Podgorza..html

Figure 3.3.4 Wharf on roundabout in Krakow [83]

Bridges are structures allow to overcome water obstacles. Due to the type of transport which moves on the support structure, the bridges can be divided into:

- traffic – when the object moves motoring,
- railway – the bridge is run rail transport,
- water (aqueducts) – the facility is run water channel,
- footbridges – pedestrian bridges.

An additional criterion for the allocation of bridges is the material used for the construction, we have:

- stone bridges,
- wooden bridges,
- steel bridges (cast iron and iron),
- reinforced concrete bridges.

Viaducts are engineering structures that allow grade-separated intersection of two roads (duplex intersection) and overcome obstacles such as dry valleys and ravines. The most famous viaduct in the world is Millau viaduct, built in the south of France, shown in fig. 3.3.5.

When it comes to construction and materials used to construct, viaducts they are no different from bridges. They are built on the same technologies and the same materials of construction.

Footbridge structures are designed to withstand loads coming mainly from pedestrians and cyclists. In Section 4.4 describes in more detail the mentioned structures.

[83] http://www.w-a.pl/aktualnosci.php?artykul=173

Figure 3.3.5. Viaduct Millau in France [84]

Wharfs are used to separate trunk roads of local roads. Their main task is to ensure a smooth and collision-free movement of vehicles and to allow movement of pedestrians in areas with heavy traffic. Flyover being built primarily in urban areas, where there is no place to build the embankment. These structures are often built as a multi--level, providing relations in all directions. The picture in fig. 3.3.6 shows the wharf over the Chartow/Żagrze. Although, the structure seems to be interesting, its beauty difficult to prove, isn't it?


Figure 3.3.6. Wharf over the Chartow/Żagrze[85]

[84] http://www.amusingplanet.com/2012/03/millau-viaduct-france-tallest-bridge-in.html

[85] http://epoznan.pl/news-news-48032-Tak_ma_wygladac_przebudowana_estakada_katowicka

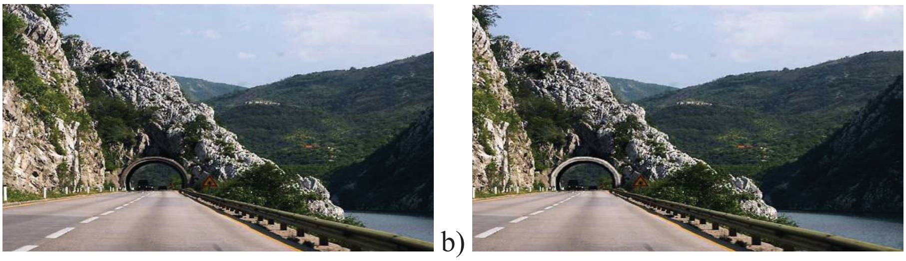
## 3.4. Tunnels *(SLK)*

Tunnels are elements of a road or rail route. They are mainly constructed in mountainous areas but also in cities, irrespective of their location. In mountainous areas pass-tunnels are built. They enable the construction of a lower grade road. Bearing in mind that in the case of railways where oblong declines are small the construction of a tunnel can be very beneficial.

A spectacular example is the tunnel under the English Channel which in known as Eurotunnel. It is 50.5 km long and links Folkestone to Coquelles near Calais. The train speed limit is 160 km/h, [Channel Tunnel, 1987].

The tunnel design is complicated. To start, let us define the concept of a tunnel – it is a structure for which the basic load is ground/water pressure. There is a variety of definitions to choose from, but they generally relate to small/short tunnels, [Hung C.J., et al., 2009].

From the car driver's perspective, of paramount importance is the ability to adapt mentally and accommodate the eye for the purposes of the entrance and travel through a tunnel. A long tunnel can arouse states of claustrophobia. For these reasons, the lighting of a tunnel is crucial. The entrance to a tunnel has to be a distinctive light-coloured portal, clearly describing the change of traffic conditions. This is especially important in the case where a tunnel is a single hollow place without separated carriageways. For these reasons, the lighting of tunnels is crucial.



a) b)

Figure 3.4.1. Tunnel entrance, Monte Negro a) Grey gate b) For the purposes of this research, the tunnel entrance was coloured white, *(by SLK)*

Figure 3.4.2. Tunnel entrance on the highway near Makarska, *(by SLK)*


Figure 3.4.3. Metro station a) Omonia, Athens b) Bank in London *(by SLK)*


Figure 3.4.4. Sitina Tunnel near Bratislava a–b) Tunnel construction b) Opening[86]

The adaptation of the eye to a brighter area is faster than to a darker one. Therefore, exit lighting doesn't need to be substantial. In the countries where there is sharp sunlight, on the entrances and departures from the tunnel anti-sun louvres are used. Vertical tunnel side surfaces are covered with a light-coloured/white glaze or painted brightly. Lines painted on the roadway also must be clearly visible in the vehicle lights.

Hazards in the tunnels include car accidents and fires as well as border situations. Car accidents increase the concentration of fumes. In these situations, it is essential to move to service bays where you can put a damaged car. The traffic slowing down due to a car accident or by a traffic jam means that appropriately responsive and efficient ventilation system must be used.

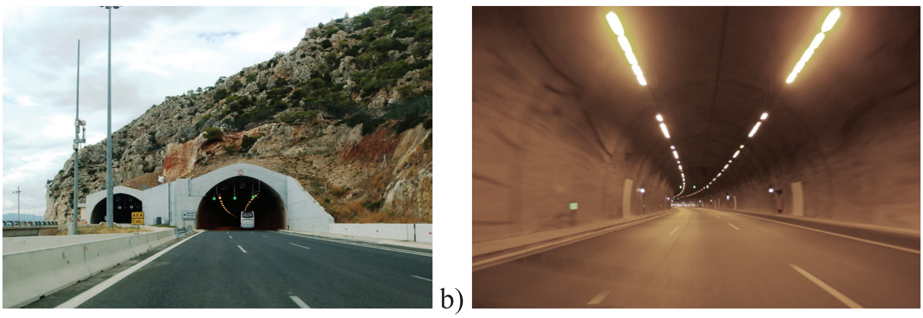


Figure 3.4.5. The short highway (Athens-Corinthos) tunnel a) portal of entry/exit b) tunnel view

[86] b: by I, MarkBA. commons.wikimedia

Fire in a tunnel is a very difficult situation. As demonstrated by the cases of fires in the last decade, a rescue operation cannot always be carried out in such a way that there are no casualties [Mont Blanc Tunnel fire in 1999].

However, in many cases, tragic situations were avoided. Thanks to the proper functioning of a ventilation system and the efficiency of auxiliary tunnels as well as effective operations of different rescue services 3 fires in Eurotunnel ended only an exhaust poisoning case and hospitalisation.

During a fire, the ventilation system must meet two conditions: first of all, it must not feed the fire and, secondly, it must provide air in such a way as to thin the smoke, which is as dangerous as fire.

As already mentioned in the first sentence, the tunnel is a very complex road construction. First – geology. A precise identification of the geological conditions and consequently the geotechnical parameters begins the design process. Soil pressure is the basic problem, related to the presence of water in various forms in the ground. The easiest situation is when soil is saturated by water. Then the usual drainage system is sufficient. In the technical sense the opposite situation occurs in the case of sunken tunnels. Then the tunnel rests on the ground and is subject to hydrostatic pressure.

Of special significance are technologies associated with the construction of the subway tunnels. The first subways were created in the late nineteenth and early twentieth century. During this period mining technologies were used. That is why it is said about the method of Belgian, German, Austrian, or English, [Lepel, 2014; Maidl et al., 2013].

Figure 3.4.6. Tubings *(by SLK)*

Historically, the construction of the undergrounds in Paris, London, Berlin and Moscow were the reasons for the development of tunnel construction technologies. In fact, the process further progresses and the nets of the underground tunnels are constantly expanded by means of ever newer technologies.

The Paris Metro, Métropolitain, was initially built by mining methods. The Belgian method was used very often.

In London Tube, in very favourable and homogeneous soils, *tubings* were used. Tubings are prefabricated elements used there for the first time.

In the case of Berlin U-Bahn the construction was carried out in loose sands which resulted in the need for adequately safeguarding walls of the tunnel. The system was devised by prof. Karl Terzaghi.

Moscow Metro is an example of a widespread use of precast concrete sections in shallow tunnels. The central Moscow underground stations were designed in relation to the political aspect. They were built as *Дворцы* for workers and peasants. They reflect the planned general prosperity with a strong reference to the historical perceptions of Soviet people.

During World War II London's and Moscow undergrounds were a safe refuge for cities' inhabitants during the bombing. Currently, tunnelling is dominated by a technology called TBM, *Tunnel Boring Machine*, [Maidl et al., 2014; Spencer et al., 2009].

a) b)

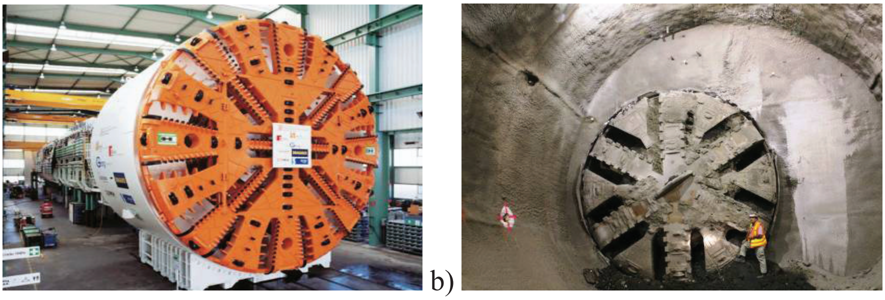


Figure 3.4.7. TBM a) Brand new set b) In use[87]

The method consists in using a self-propelled machine with a movable rotating disc. The rotating disc can be of a small diameter, less than 1 m – micro tunnelling, but also of a diameter amounting to 15 m was used for drilling the soil or rock. In practice, TBM is designed individually depending on the soil/rock. It was often used only for one particular task.

## 3.5. Road users' service area *(MK)*

Depending on the technical grade of a road and the anticipated needs of its users, a road can be provided with facilities and equipment for traffic service. These objects and devices include in particular [Dz.U. 43, 1999]:

- road users' service area,
- toll area,
- points of truck inspection, parking bays,
- bus bays, tram platforms,
- bus loops, car returning places,

[87] a: http://www.dr-sauer.com/files/drsauer/public/content/file/326/upload/sbpt-west-and-tbm800 x533.jpg, b: http://tunneltalk.com/ images /Sacramento/TBM-in-Receiving-Shaft.jpg

- passing places,
- pedestrian crossings.

The above-mentioned facilities and equipment depending on their purpose, can be localized within the crown, as well as outside the crown of the road. Facilities and equipment must be located in the appropriate position with regard to the required distance from the edge of the roadway. Buildings and other obstacles that reduce visibility should be located outside the required field of vision. They should not cause danger for the safety of road users.

This section focuses mainly on the road service area (RSA) description. The aesthetics of the design of the RSA refers to both the visual effect as well as ergonomic use. These structures are intended mostly for motorways and expressways. There are no contraindications to build them on roads of lower technical classes with a big volume of traffic. The distance between adjacent road service areas is defined in [Dz.U. 43, 1999]. RSA located near a motorway or expressway should ensure service of road users in a specified range. RSA may have different functional characteristics depending on its type:

- RSA I – the leisure function area: equipped with parking spaces, manoeuvring roadways, recreational equipment, sanitary utilities and lighting; it is allowed to put in small catering facilities;
- RSA II – the function of leisure and service; facilities equipped with the same facilities as RSA I, and the gas station, vehicle service station, catering and shopping facilities, tourist information;
- RSA III – the function of leisure and service: equipped with the same facilities as RSA II as well as accommodation facilities, and, depending on the needs, a post office, a bank, tourist offices and insurance offices.

Ergonomics of road service areas involves at least ensuring the safety of users entering, leaving and moving in their area, offering hygienic facilities, enabling leisure, with a possible extension of the range of services. RSA ergonomics is also associated with economic maintaining of the required cleanliness and standards of use, at the lowest possible management cost. Therefore, it is not always on both sides of the road that the highest standard RSA are designed.

It is accepted – and it has an economic basis – to construct RSA with lower standard equipment on one side of the road and the RSA with a higher standard on the other side. In this case, a safe passage from one side to the other must be ensured. Therefore, RSA I facing RSA II or RSA III must be connected with a collision-free pedestrian crossing for safety reasons. It is also possible to build RSA on only one side of the road. In such a case an access from the other side of road must be provided.

Designing traffic safety for RSA is linked to an appropriate entry from the road to RSA and a re-entry onto the road. An entry and an exit from RSA cannot be located in places that threaten the safety of road users, in particular:

- in the area of the impact of an intersection or a node point,
- where a distance of visibility is necessary to enter a road,
- on a road section with a gradient vertical alignment of more than 4%,

- no closer to the top of the arch convex than the required distance of visibility to stop,
- along an additional lane.

An extension of the merging ramp on which it is possible to accelerate, it should be an emergency lane, and an additional lane – a paved shoulder whose dimensions are described in [Dz.U. 43, 1999].

The organization of traffic within RSA has a significant impact on how safely, conveniently and easily users get to the zone of functional services. The classical type of such a system is a drive-through system. The main traffic moves in one direction from the entrance through different zones to go on the road. In this system it is not possible to revert and come back to the zones one has just left. Limiting the freedom of movement around the area through a traffic system in RSA is a serious drawback. Much more convenient are RSAs with a bypass traffic system. There is a road inside a loop encircling each zone or running between the zones constituting a kind of the local bypass. From the main road, access roads lead to various functional zones. A disadvantage of this system is the complexity of roads, intersections and junctions [Marchwiński 2006].

Figure 3.5.1. Parking spaces for the disabled near sanitary objects, *(by MK)*

An ergonomic and aesthetic design of RSA means also an appropriate parking area solution. In each row of parking spaces for cars there should be provided not less than two car parking spaces for the disabled. They should be marked and situated close to the access to public buildings. Communication paths to farm buildings for people with disabilities should have appropriate shape. Depending on the needs, RSA should be equipped for the technical inspection of vehicles spaces and parking spaces for vehicles carrying hazardous materials. RSA should also be equipped with fire protection equipment. Surface water and domestic sewage must be cleaned before discharge into the receiving water or the ground accordance with the provisions of the Environmental Protection and Management. Therefore, it is necessary to adjust a drainage solution with parking spaces and internal roads.

Aesthetic feelings of the RSA users should be positive. RSA should enable drivers and passengers to rest when they are on the road. An important aspect of planning is to maintain a spatial land use. It should be born in mind in the case of RSAs located in rural and underdeveloped areas. RSA spatial solutions are the result of taking into account the functional and utilitarian prerequisites. The issues of an aesthetic and spatial composition are often ignored at the design stage, which is a pity, because such an approach could reduce the possibility of the formation of such objects.

Creation of an interesting concept characterized by a compositional space is not necessarily mean a complex shape concept. It may be limited to a simple figure (square or rectangle), in which the central part is divided by the road into two parts. RSA buildings and a green area can be shaped with great arbitrariness. An architect/engineer may increase or harmonize the dynamics of the building composition.

A functional and spatial organization is one of the most important aspects of the urban and architectural design of road users' service areas. The spatial distribution of individual elements of RSA and their interrelatedness is the essence of the project and warrants comfort, the clarity of solutions, but also safety. RSA organization (mainly of type II and III) is generally based on the principle of functional zoning. This involves dividing relevant functional areas into clear zones: a parking area, a leisure or leisure-service zone and a vehicle service station. Zones are connected by internal roads. This rule introduces a spatial order conducive to a clear division of functional program elements which are arranged in the zone. The distribution of zones with respect to each other and a connection to the entrance from the highway allows to specify two basic types of RSAs [Marchwiński 2006]:

- „S – P – R" (petrol station – parking – rest area), according to the order of functions from the entry on.
- „P – R – S" (parking – rest area – petrol station), in which the area of petrol stations/servicing of the vehicles is at the end of a RSA site.

There is another approach in the use of the functional zoning principle. This is the principle of approximations or a withdrawal of functional zones in relation to the road. Road is considered to be the main source of noise. The noise level may be one of the design guidelines. The principle of acoustic zoning consists in dividing RSA into quiet and loud areas, establishing a hierarchy and setting the appropriate location zones. In accordance with the above principle, the loudest area is put closest to the highway and the quietest one away, if possible [Marchwiński 2006]. The loud zone includes arterial roads within RSA and a parking area for trucks and buses. Intermediate zones act as a noise buffer. There are service stations and vehicle maintenance stations, an internal road network for slow traffic and a parking lot for cars. Quiet zones include a rest zone, sometimes catering and accommodation facilities.

The aesthetics of RSA is also influenced by the architecture of buildings within the area. Depending on the approach of architects, the architecture of RSA objects captures the spirit of the automotive industry (which could be foreign to the geographical location) or expresses the specificity of the place, its landscape, and cultural individuality.

For drivers and travellers who travel hundreds of kilometres of roads, moving in an anonymous landscape of a freeway or an expressway, RSA acts as an information board and a showcase of the place where it is located. The architectural character of RSA defines primarily service facilities and the roofing of petrol stations, natural materials (stone, wood) and irregular forms of greenery in the surroundings. The spatial form of RSA architecture and form of details should not provoke. RSAs architecture should foster a sense of peace and relaxation, allowing for a momentary escape from driving on an expressway [Marchwiński 2006].

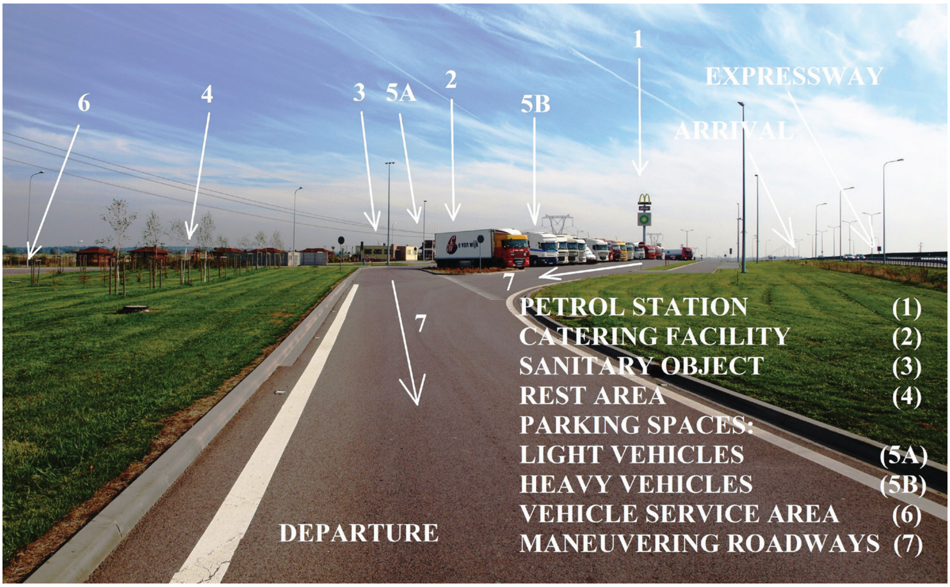



Figure 3.5.2. Road service users' area organization, *(by MK)*

Supplementary to the discussed above aesthetic design issues of RSAs are issues related to the design of greenery, pavements, lighting, small architecture and labelling. Flora acts primarily as a visual barrier, a resting zone element, an acoustic barrier and an element of spatial composition. Small architecture, i.e. sheds, benches, tables, dustbins, elements of the playground, fences, etc., besides its utilitarian functions contributes to the climate of RSA. A similar role is played by neon signs, lamps and small garden lamps. Road signs influence safety and orientation.

a) b)

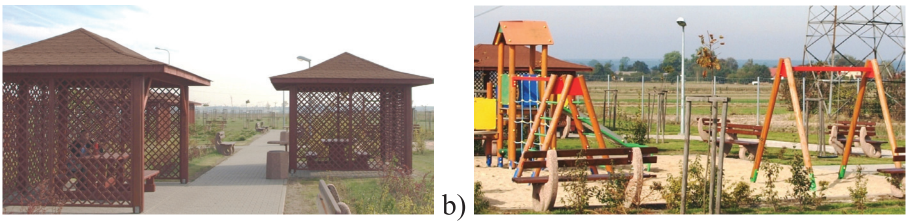
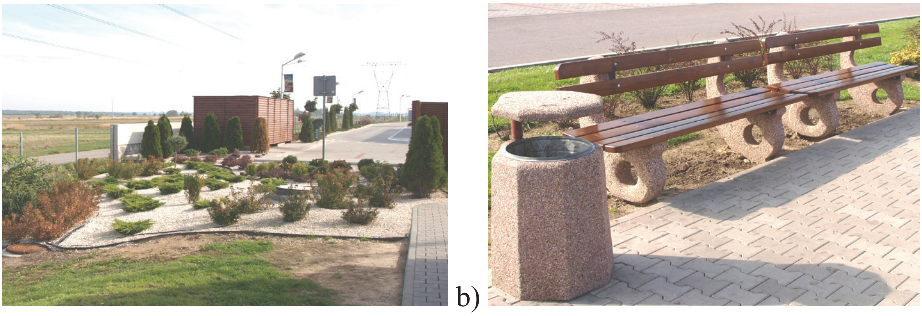


Figure 3.5.3. Landscape architecture: a) arbors, b) playground, *(by MK)*

Designing service stations is therefore a process in which the aesthetic aspect (urban and architectural) should play no less a role than the ergonomic exploitation aspect. It is necessary to look for optimal solutions primarily with regard to safety and comfort. Important elements of the RSA aesthetic design process are: the functional program, setting buildings, traffic management, equipment, zoning, the system of connecting functional zones, etc. Approaching the design of RSA only from the functional and operational perspective can cause a disfigurement of the environment. When designing RSA, the environment spatial composition and architectural objects, an attention to detail and thoughtful solutions concerning the landscape architecture should be taken into account, in addition to their function and aesthetic reasons.



a) b)

Figure 3.5.4. Details: a) decorative plants, b) equipment: trash bin, benches, *(by MK)*

Different types of road users' objects and equipment that are not discussed in more detail in this chapter include:

- adjacent roadway or separated parking bays,
- bus bays with platforms with devices to protect pedestrians from the weather (shelters)
- exit road to a observationpoint/deck, worship or national memorial
- bus loops,
- car turning places,
- passing places,
- pedestrian crossings (on the level of the road – with traffic lights or without signalling, collision-free – underground – tunnel or over ground – footbridge).

## 3.6. The travel speed and aesthetics of road *(MK)*

Due to the ongoing development of the road network since the twentieth century, and now, in many cases, inappropriate condition of such a network (damaged surfaces, poor lighting, inadequate labeling scheme, illegible information) and thus concerns of the International Road Federation (IRF) as to road safety, the scientific world[88] has developed a new approach to this problem. Interdependence relationship road – the driver

[88] Michel, Novak, 1975; Naatanen, Summala, 1976; Klebersberg, 1982; Evans, 1991; Adams, 1985, 1995; Wilde, 1994, 1996; Hedlund, 2000; van Viet, 2000.

– vehicle – environment are examined by the International Cooperation on Theories and Concepts in Traffic Safety (ICTCT).

On the basis of studies (described in chapter 3.3) it has been concluded that the speed chosen by the driver is affected by such road parameters as visibility, curvature, width, number of lanes, evenness. The location of the road – urban/suburban area, developed/undeveloped area – is also of considerable importance. In terms of aesthetics the road surroundings also influences the driving speed.

The relations between road aesthetics and driving speed was the subject of research in Sweden[89] carried out on free running passenger cars while they travelled on a road section with high aesthetic values (blossoming trees on both sides of a well-maintained road) and without aesthetic values (after the end of the blossoming period), as well as on the road sections in the first case aesthetic but dangerous and in the second case not aesthetic and dangerous. The research showed that drivers reduced speed on the observed section by 5% in the period of tree blossoming compared to the period after blossoming.

It follows that the aesthetic surroundings of the road, especially involving natural forms of nature, can have a positive effect on drivers, their level of satisfaction and behavior, which can result in reduction of the driving speed in order to prolong (consciously or not) the time spent in the environment of high aesthetic value.

Theoretical and empirical research on the impact of road safety on the aesthetics with elements of transport psychology and the studies of how dynamic components of road image influence drivers was conducted at the Technical University of Krakow in Poland under the supervision of Zakowska [Zakowska, 2001]. The results of this study allow us to conclude that, in generally, driving speed is higher on road sections in rural and undeveloped areas, with many lanes, rather than in urban and developed ones, on narrow roads.

The speed selected by the driver is influenced by road parameters such as visibility, curvature, width, the number of lanes and evenness of the surface. Road location is also of a great importance: whether in urban or rural, developed or undeveloped areas. The road surroundings in terms of aesthetics also have an impact on the driving speed.

The conclusion is that aesthetic surroundings of the road, in particular including some forms of nature, may have a positive impact on drivers, their level of satisfaction and their behaviour, which may result in speed limit reduction in order to prolong (consciously or not) the time spent in the surroundings of high aesthetic value.

On the basis of these proposals road designer has considerable responsibility for safety in road traffic.

Designing 2D visualization method and the form of intelligent four-dimensional digital models of virtual space are discussed in detail in Chapter 5.

[89] Dutch programme of pilot studies started in 1999 ICTCT Augustsson, 2000.

## 3.7. Vernacularism of local roads *(SLK)*

The term “vernacularism” comes from the Latin word *vernaculus* which means native or domestic. In accordance with the commonly used definition, vernacular architecture is “architecture without architect, anonymous, created without design, rooted in the tradition of the society and constituting a sum of construction, functional and aesthetic experiences which pass from generation to generation” [Kurzatkowski, 1985].

The art of building local roads in the vernacular spirit is an art deeply rooted in the local tradition and created by the local builders. As a rule the materials available locally are used for construction of local roads, which also has a direct impact on the construction technique and the finishing method. Such materials are, among others, wood, earth and even snow. The roads are adjusted to the conditions of a given area and to the needs of users. Designers, builders and investors of such roads are mainly anonymous and often it is the same person. Such a person usually does not have any academic preparation or experience which goes beyond his/her own region. The road model is not theory but hands-on experience and knowledge of tradition.

Currently vernacularism, neo-folklore, the idea of “slow design” means programme references to the local solutions and to the regional tradition, respect for the context of the surroundings, selecting blocks, finishing materials and colours in harmony with the existing structures and the surroundings. Neo-vernacularism is an answer, and maybe even a solution, to the problem of the modern global architecture, an escape from the trap of globalization and a search for own identity. Observations made and experiments carried out by previous generations take into account such factors as topography, climate, light or tectonic, which are decisive for the compliance of form and function. Application of local materials, repeating and processing the repertoire of details and typical features create the sense of material culture continuity. Respect for the tradition and history strengthens the sense of identity. In the world without borders, in the global village, this seems particularly important.

Examples road structures of vernacular style are shown below (Fig. 3.6.1, 3.6.2).

Figure 3.7.1. Culvert deeply rooted in the local tradition, county road to Jableczna in Poland (*by ALT*)

Figure 3.7.2. Road deeply rooted in the local tradition with cross wayside shrine, county road to the Monastery in Jableczna in Poland (*by ALT*)

Let us see how dictionary defines the word “vernacularism”:

Thesaurus.com [90], synonyms are: atrocity, barbarity, brutality, catachresis, coarseness, corruption, cruelty, impropriety, inhumanity, localism, malapropism, misusage, misuse, primitive culture, provincialism, solecism, uncivilizedness, vulgarism.

Collins[91]: – nothing found.

Merriam-Webster.com[92], synonyms are: conversational, informal, non-formal, non-literary, unbookish, unliterary, colloquial, vulgar.

For the sake of this chapter the word “vernacular” is defined as: not fully professional, local, provincial, primitive. But at the same time: efficient, adequate, based on the tradition and the resourcefulness of a community. Here vernacularism has a positive connotation.

By “local roads” one means all roads that are used by local communities. According to the technical classification they are tertiary roads, whatever it may mean. They are mostly rural and forestry roads. What is characteristic of these roads is their low quality in terms of geometry and paving.

Roads running through rural areas are irregular due to historical construction. Because of the private ownership of land, shaped over the years and the morphology of the terrain the previous system is conserved. This means that often basic standard requirements are not met. This applies to minimum horizontal and vertical curve radiuses, transverse and longitudinal slopes, sufficient traffic visibility for safe driving.

[90] http://www.thesaurus.com/browse/vernacularism, [20.10.2015].

[91] http://www.collinsdictionary.com/dictionary/english/vernacularism#examples_box, [20.10.2015].

[92] http://www.merriam-webster.com/dictionary/vernacular, [20.10.2015].

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The ability to extract a road shoulder is sometimes problematic. Roadside draining ditches occur rather accidentally As shown in Fig. 3.7.3, there are no sidewalks or footpaths. Therefore, a rural road serves pedestrians, cyclists, passenger cars and heavy farm machines. It is certainly not conducive to traffic safety, especially for pedestrians and cyclists. Generally, there are no street lamps. Very rarely horizontal markings are used on the road pavement, usually in the city outskirts. These factors are decisive with respect to the vehicle speed which should not be higher than 40 km/h, but in practice it is sometimes different. The amount of rural traffic is small, in not insignificant. It is estimated at a few hundred vehicles per day. In summary, rural roads are characterized by slow movement, diverse in terms of user types and safe as at the traffic participants are not anonymous.

The maintenance of rural roads is a complex technical and social problem. In the technical sense, and above all with regard to the current repairs of damaged roads, it actually does not exist. Once built, a road functions until its full consumption. The wear is caused by heavy vans and the fatigue of used bituminous paving materials. In the photos shown above a fatigue crack mesh is visible. The so-called winter maintenance is carried out by means of agricultural machinery, which is easily adapted to the role of the bulldozers and available in villages. Snow removal is funded by the local authorities or carried out on the basis of a mutual neighbourly assistance. It is not uncommon that snow is removed manually by shovel or using small machines for snow removal. Anyway, as a result of these activities, children can reach the nearest bus stop and an ambulance can get to the patient. Environmentally it is a very favourable situation because essentially no salt is used for road de-icing. However, white road surfaces are not uncommon.

In terms of aesthetics, indisputably, rural roads convey the sensation of sensual longing, which is caused by their contrasting nature to the ubiquitous rat race in all municipal societies. The closeness of nature, the scent of the countryside and the sounds make hundreds of weekend trekkers or cyclists roam the rural roads. It is nothing extraordinary: for centuries artists and ordinary people from cities have experienced the pleasure of staying in the country. In in this respect nothing has changed. Only rural roads, despite the constant raising of their standards, are still vernacular.


Figure 3.7.3. Rural roads a–b) gravel pavement c–d) bituminous surface, *(by SLK)*

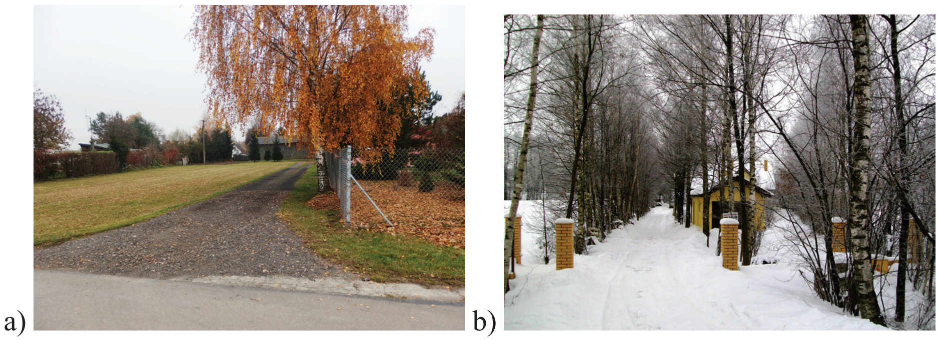


Figure 3.7.4. Commuting to property a) in autumn b) in winter, *(by SLK)*

# 4. Aesthetics of bridges

## 4.1. Static scheme choice *(MK)*

"Static scheme" refers to the mechanical concept of structure. In short, it is a decision regarding a type of foundations, supports and carrying elements. It can be a beam, a frame, a shell, an arch or any other type of a carrying element. However, the designer has to decide about the structure mechanism, whether it is bridge, a building or a swimming pool. The choice of a static scheme, supplemented by a decision on materials to be used, strongly influences the future image of a building.

Referring to [Łagoda, 2001] 90% of bridges are structures located in non-representative places. For these objects, a static scheme as well as the general form of the object is not selected according to the intended good aesthetic sense. It is associated mainly with the technical requirements, the lowest price and the lowest maintenance costs. In addition, the second and the third do not always go hand in hand. A designer or design teams, shaping these objects in the privacy of their offices, do not necessarily consult design ideas, seeking only to fulfill the objectives of strength and functionality. Only in the case of objects more transparent, object contractors expect that the new construction will arouse admiration or at least will be positively received by users. At the design stage of less visible objects there is usually not enough money to take aesthetic factors into consideration. Also, shorter design deadlines do not allow for the awakening of the designers's sense of mission to design something different than a structure which will be perceived indifferently or negatively. Moreover, in the case of small and medium periods of time it is much easier to solve technological and endurance issues than consider an aesthetic problem. The aesthetics of bridges are dealt with, among others, in [Wasiutyński 1962, 1971, Leonhardt 1968, 1982, 1991] and more recently in [Łagoda 2001] and [Łagoda, Łagoda 2014]. This chapter deals with the principles of the selection of a static scheme of the bridge structure in the landscape.

In shaping the form of bridges one should be guided by the principles described, among others, in [Wasiutyński 1962, Głomb 1990, 1991, 1994, Łagoda 2001]:

- the principle of the veracity of the form including the rules resulting from the function and the conditions of the construction and operation of a bridge (rule should be treated as parent),
- the principle of entirety regarding the visibility of all elements of the form and their interdependence,
- the principle of simplicity recommending uncomplicated forms and a small number of elements,
- the principle of the legibility of the form which applies to a simple recognition of the interdependence of the form elements, function elements, and the balance of internal forces,

- the principle of the avoidance of emptiness involving the rejection of not understandable forms,
- the principle of regularity covering the characteristics of equality which exists between the form elements: colours, lights, etc., giving a rhythm and proportions.

Understanding of the above principles is necessary. However, it is not always sufficient to achieve the result where the object meets its expectations, fulfills the design and social acceptance requirements. Furthermore, the designer's involvement, their sense of beauty, experience, knowledge of the object erection environment is indispensable to achieve a total success.

These principles should be considered together. They concern overlapping and complementary areas. These rules apply to both the object as a whole and every element separately as well as the environment of the object, which becomes its permanent feature.

New roads built in Poland, of which the bridge structures are an integral part, are in the case of most national roads (expressway or highway) rebuilt provincial roads and stretches of new urban roads to town bypasses. They are located in urban, industrial, agricultural, forest and mountain areas. These roads also cross regions culturally different. Such conditions necessitate the use of carefully chosen design solutions.

The selection of the bridge static scheme is a major problem in designing. This applies mainly to objects situated on the main roads (motorways, expressways). Basically, the selection is made between the two schemes [Łagoda 2001]:

- three or four span viaducts of light extreme supports, if the central reservation does not provide intermediate support,
- one or double span viaducts with solid abutments.

The first solution is suitable for routes leading to wide trenches with small angle slopes. In the case of a dual carriageway carried out in a flat terrain and carrying cross--roads above it, it is recommended that one or two-span object with solid abutments be placed on the contact area with the road embankment. If the road runs in a deep trench with steep slopes or between retaining walls, it is recommended to design single-span bridges. In such a case, slender beam bridges and the single-span openwork arch are the best, Fig. 4.1.1.a.

If the width of the central reservation is relatively small, it is recommended to avoid the intermediate support in its area. This is mainly because of the requirements of traffic safety, especially in the case of routes for high-speed traffic. In this case, it may be best to consider a large span frame construction, Fig. 4.1.1.a.

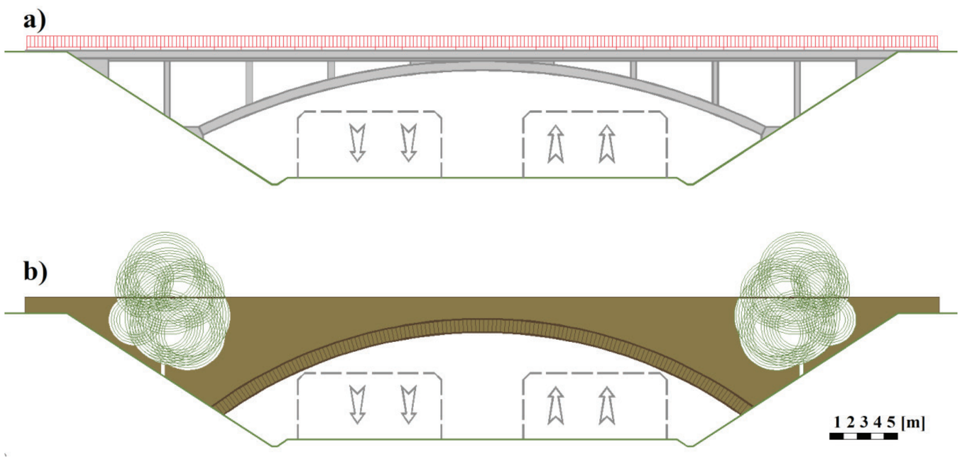


Figure 4.1.1. One span arch viaducts a) openwork, b) solid

In addition to selecting a static scheme in itself, it is important that the proportions of the structure are also carefully designed. Arches with front walls (Fig. 4.1.1.b), single-span beams or frames are indicated in the cases where it is expected to emphasize the gravity and solidity of the object. In such a case, the extreme supports must be properly designed. Abutment in such cases should be solid and clearly separated from the supporting structure, Fig. 4.1.2.

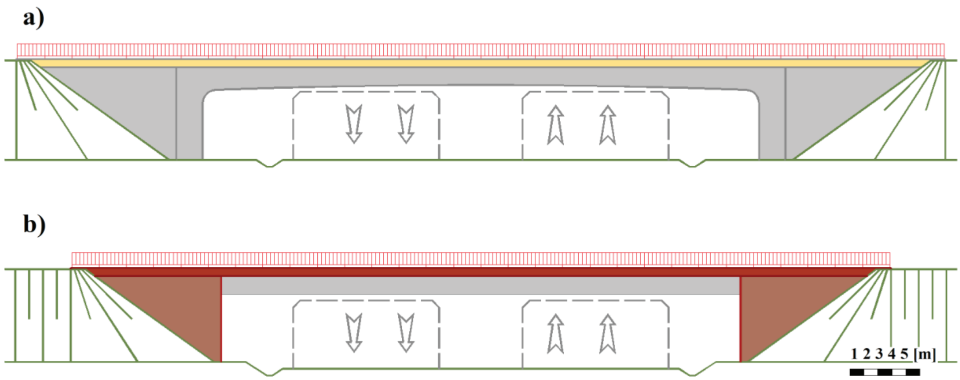


Figure 4.1.2. One span viaducts: a) frame, b) simple supported light beam

A light arch or framework structure derived from the arch (Fig. 4.1.3) is recommended to be used in the cases where it is required to build a lightweight, slim and elegant structure. Simple supported beams or slabs should be designed with an appropriate uplift. These structures are less slender than a frame or an arch. Therefore, it may cause a negative impression.

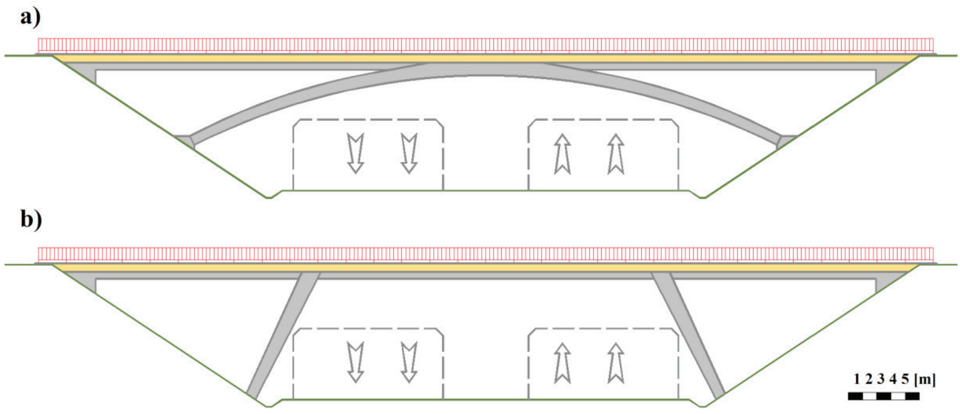


Figure 4.1.3. Three span frame viaducts: a) derived from arch, b) simple

In the case of a road truss structures are often used for footbridges. For the traffic, trusses are less preferred [Łagoda 2001]. This is due to the lack of the legibility of form and the distribution of internal forces. They are the least acceptable in the public's view, and because of their illegible structure they are a visible intercalation in the landscape, Fig. 4.1.4.a.

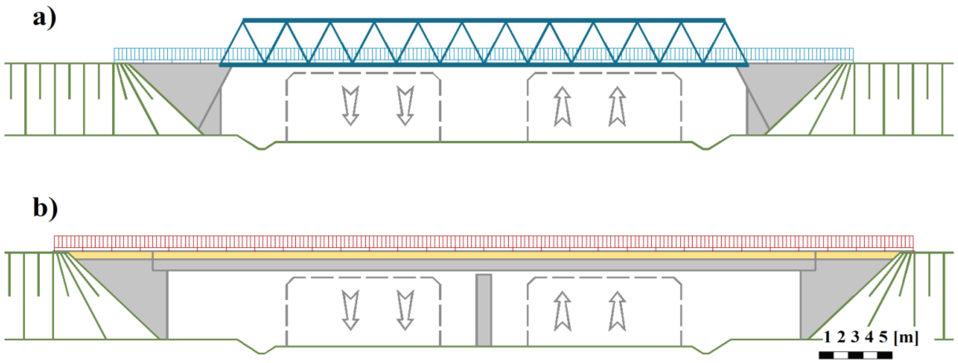


Figure 4.1.4. Viaduct: a) one span truss, b) two span continuous beam

Suspension and cable-stayed structures (Fig. 4.1.5), must be designed with utmost care. These structures over roads occur rarely as unusual and act as an additional feature of characteristic points (landmarks). In areas of natural landscape, every structure, whether suspended or cable stayed, can significantly disrupt the harmony. In urban areas static schemes of this kind are easier to adapt. But not always object of this type must meet the hopes vested in it. It may be unpleasant to watch, not fulfilling its aesthetic role.

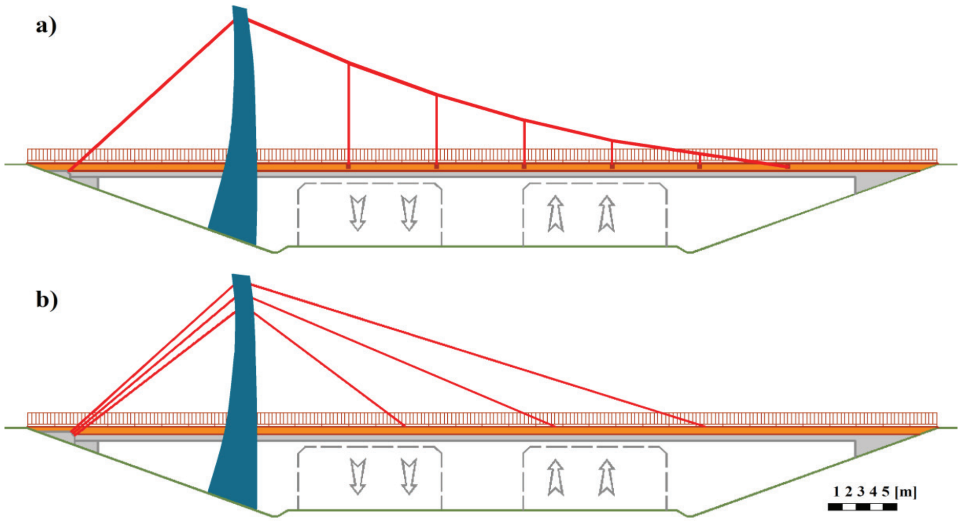


Figure 4.1.5. Viaduct: a) suspension structure, b) cable-stayed structure

## 4.2. Hanging bridges and suspended as an icons of their times or regions of the world *(MJ)*

Analyzing the definition of the word bridge for purely technical have a very simple term – bridges are structures that allow you to cross the water obstacle in the form of lakes, rivers, bays, etc. However, if we look at it from a different perspective, we read it as one of the most beautiful and at the same time the most difficult design engineering to design and build. These beautiful structures can be divided in many ways, on the number of spans, the static diagrams, after the manner of carrying loads. It is not disputed that the most spectacular factor affecting the visual perception has a span bridge. That's what makes span length in delight more than one observer. Many people travel the world to be able to see objects that break the structural barriers, once beyond reach. Such structures are just hanging bridges and overhead. Each such object is unique in its kind. Their size is associated with strength while maintaining the delicate notes. Both bridges suspended and hanging, have to bear unimaginable burdens, caused by the impact force of the wind, temperature, load supplies. It seems, therefore, that there should be a massive structure, not less, however, is not entirely correct idea. The length of the span has a decisive influence on the material they will be executed. Each of them, however, has different physical properties, eg. tare weight, tensile strength or resistance to atmospheric agents. In the long engineering objects choice of material for the construction of the span depends primarily on gravity. Such a structure must be designed in such a way as to be the lightest and simultaneously resistant to load constants and variables. Designing such an object is quite a challenge for many designers. Bridges that have preserved the right balance to the total weight overall dimension are called slender structures. This is very important for architectural and visual aspect. Bridges hanging and suspension are often referred to as "icons" of cities in which they are located. Such structures attract crowds of tourists, enthusiasts, engineers or designers from around the world. Global example is the Golden Gate hanging bridge linking San Francisco with Marin county in the United States shown in Fig. 4.2.1. In accordance with the information provided in *https://pl.wikipedia.org/wiki/Golden_Gate_Bridge*, Golden Gate annually visited by over a million tourists. In Poland, the most famous bridge is suspended Solidarity Bridge in Plock, which is shown in Fig. 4.2.2.

Figure 4.2.1. Hanging bridge – Golden Gate *(by Alicja Filipowska)*

Figure 4.2.2. Bridge of Solidarity in Płock [93]

[93] https://pl.wikipedia.org/wiki/Most_Solidarno%C5%9Bci_w_P%C5%82ocku

Keep in mind that tourism development in localities where there are these beautiful structures is the only addition to the functions they perform. These huge facilities allow you to overcome a route that used to be impassable. They are very important point in the development of communication, breaking down all barriers of ethnic, social, cultural. They allow urban development in economic, tourist, scientific. They are an integral part of the city, which is equated directly with him. Tab. 2 shows examples of the lad 's longest hanging bridges, and Tab. 3 suspended ten longest bridges in the world.

Table 2 The longest hanging bridges in the world[94]

| ***Bridge*** | ***Country*** | ***Span length [m]*** | ***Total length of the bridge [m]*** | ***Completion Year*** |
|---|---|---|---|---|
| Akashi Kaikyo | Japan | 1991 | 3910 | 1998 |
| Xihoumen | China | 1650 | 5300 | 2009 |
| Great Belt | Denmark | 1624 | 6790 | 1997 |
| Izmit Bay | Turkey | 1550 | 3300 | 2014 |
| Yi Sun-Sin | South Korea | 1545 | – | 2012 |
| Runyang | China | 1490 | 35660 | 2005 |
| Nanjing Fourth Yangtze | China | 1418 | – | 2012 |
| Humber | Great Britain | 1410 | 2220 | 1981 |
| Jiangyin | China | 1385 | 3071 | 1999 |
| Ts'ing Ma | Hong Kong | 1377 | 2160 | 1997 |

Table 3 The longest suspension bridges in the world

| ***Bridge*** | ***Country*** | ***Span length [m]*** | ***Total length of the bridge [m]*** | ***Completion Year*** |
|---|---|---|---|---|
| Russky Island Bridge | Russia | 1104 | 3100 | 2012 |
| Sutong | China | 1088 | 8146 | 2008 |
| Stonecutters | Hong Kong | 1018 | 1596 | 2009 |
| Edong | China | 926 | – | 2010 |
| Tatara | Japan | 890 | 1480 | 1999 |
| Pont de Normandie | France | 856 | 2143 | 1995 |
| Jingyue | China | 816 | 4302 | 2010 |
| Incheon | South Korea | 800 | 21380 | 2009 |
| Xiamen Zhangzhou | China | 780 | 10000 | 2013 |
| Zolotoy Rog | Russia | 737 | 1388 | 2012 |

[94] http://mosty.inzynieria.com/cat/19/art/27014/najdluzsze-mosty-wiszace-swiata

Figure 4.2.3. Manhattan Bridge and Brooklyn Bridge *(by Paweł Filipowski)*

## 4.3. Slight, slender structures (footbridges) *(MJ)*

Footbridge are engineering structures designed to carry loads from a crowd of pedestrians or cyclists. Footbridges are integral part of public transport. They are often a showcase of cities or regions where they are located. These structures apart from the communicative function also may be of a promenade equipped with benches, flowers and spectacular lighting [Flaga 2011]. Their design should be adjusted so that in addition to utility functions meet all the aesthetic and architectural aspects. Such facilities should be ideally integrated into the surrounding landscape. Design of footbridges is a very difficult task, because it requires the cooperation of the constructor, architect and urban planner. This cooperation is based primarily on mutual, engineering understanding and respect.

The task of the architect is to create a project that will be characterized not only naturalness and functionality, but also economical and harmony with the surrounding area. The integration of the object can be done in two ways [Flaga 2011]:

- principle of adjustment to the existing situation, with a view to the lack of interference in the environment,
- principle of contrast, which is based on a complicated, inconspicuous design that clearly stands out from its surroundings.
- Analysing the above methods can be distinguished additionally [Pyrak 1989]:
- principle of "signaling element", whose task is to point signal to the driver on long and monotonous stretches,
- principle of "tradition," which is based on the use of traditional load-bearing systems, resulting from the existing traditions of a given functional area,
- principle of "the domination of the creator", which is based on full freedom in the choice of the carrier by the designer. Designer creates a new, unique work, which usually does not harmonize with the surrounding area,
- principle of "domination of the landscape", refers to objects located on undeveloped areas that can not interfere with the existing landscape.

The task of the architect is extremely difficult because it must meet the requirements for a harmonious insertion into the object, and at the same time meet the demands of functionality.

The continuous development of new technologies contributes to the formation of structures with unusual shapes with different materials. The results of such a development are considerable difficulties in the design of footbridges. These structures are becoming lighter and slender, while more susceptible to the effects of wind power. Sometimes the design of a small footbridge is more problematic than design road or railway bridge. Below there is an example object that meets the above criteria.

Figure 4.3.1. Footbridge in Szczebrzeszyn *(by SLK)*

According to the existing provisions of the footbridge width should not be less than 1.5 m, and for walkways for pedestrians and bike 3,5 m. This is the minimum width that provides comfort to move around the premises. In fact, the above-mentioned structure designed with a width of 3.0 to 5.0 m [Flaga 2011]. Every new building must meet all criteria for access and be accessible for disabled people.

Due to the high degree of freedom in geometric shaping of footbridges in contrast to bridges, footbridges can take diverse character in the plan. Examples of structural systems diagrams shown in the figure below.

Selection of the appropriate static scheme depends on many factors. The most important of these are:

- nature of the location of the object,
- economic considerations,
- span obstacles to overcome,
- type of obstacles to overcome,
- architectural considerations.

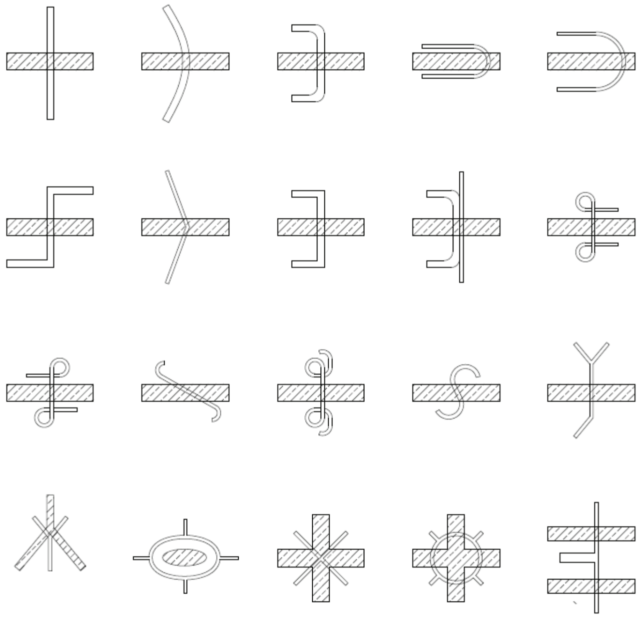

Figure 4.3.2. Schemes of construction systems of overpasses [replik from Flaga 2011]

The most commonly used regimes supporting footbridges are:

- beam systems,
- frame structures,
- truss structures,
- bends,
- construction girders,
- Tension – rod- structures,
- hanging structures,
- mixed structures.

Nowadays, the most popular are rod-tension constructions. These include hanging and suspended structures. These beautiful objects attract many tourists and enthusiasts. Figure 4.1.1 – 4.1.5 shows an example of regimes applied in the construction of footbridges.

In many cases it is difficult to distinguish whether the object is a footbridge or a bridge. Polish standards do not classify footbridges in terms of dimensions, so we can come across the footbridge with large width. If we look at this aspect in relation to charges of bridges, we could make some division. Due to the varying width of loads by [95] engineering objects can be classified as follows:

- with a width of less than 2.5 m is called footbridges for pedestrians,
- with a width of 2.5 m – 4.3 m is called footbridge foot-ride,
- with a width of more than 4.3 m is called a bridge.

[95] T. Michałowski, as above

## 4.4. Abutments, pillars, pylons as well as carrying-decks *(MJ)*

### *4.4.1. Abutments*

The abutments are classified as extreme support bridges. Their main task is to move on subsoil all the loads acting on the bridge. They act as an intermediary between the road and the subject. Due to the important function they perform, they must be resistant to the action:

- weathering,
- water,
- pressure floes,
- strokes rolling river,
- strokes rail and road rolling stock.

Extreme supports, because of the shape can be divided into:

- massive abutments made of stone, brick, concrete,
- abutments of reinforced concrete,
- in the form of supports connected to the span in a monolithic way.
- lightweight reinforced concrete abutments,
- shaped retaining walls.

Construction form abutments depends primarily on the height of the embankment and the object that needs to move loads as well as vertical and horizontal displacements, which must be "lost". We can distinguish [Madaj, Wołowicki 2003]:

- massive abutments (transmural),
- sunk abutments.

Figure 4.4.1. Bridge in Dorohucza – flooded abutment *(by SLK)*

The difference between the above mentioned types is relatively large. The abutments sunk beyond a name that speaks for itself, are embedded in the embankment, reduce earth pressure acting on the beachhead. This has a very large impact on economic factors, since the material consumption is much lower than in the second case. This is due to the smaller dimensions of the individual components abutment example. The body, which may be narrower. The disadvantage of the design of such structures is the reduction of light bridge over the span length. An example of a sunken abutment in the embankment shown in Fig. 4.4.1.

Massive abutments are in a sense the opposite of embedded, because they do not adversely affect the bridge clearance below an object, but they are more expensive in economic terms. The construction of the abutment body is bigger, which affects the size of the foundation.

Abutment consists of seven basic elements, as shown in Fig. 4.4.2. The outpost enters [Madaj, Wołowicki 2003]:

- foundation (1),
- a front wall, called the front (2),
- wingwalls (3),
- wall gravel (4),
- cap (5),
- lower bossage (6),
- bridge approach slab.

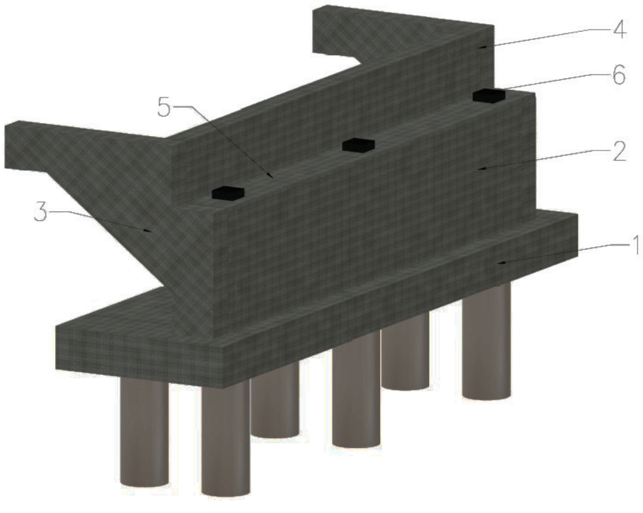


Figure 4.4.2. Structural elements of abutment brak numerów *(by MJ)*

The size of the foundation depends primarily on the forces transmitted through the beachhead, but also on bearing capacity. abutments move following forces:

- gravity (G)
- vertical and horizontal earth pressure (Gn Gn1, Pn, Pn1)
- load depth of cover,
- water load in a situation, when the soil is saturated with water,

- load transmitted through the bearings:
  - dead weight span (Rg)
  - moving load (Rp)
  - braking force / acceleration (Ph)
  - side impacts,
  - friction in the bearings (T),
  - centrifugal force when the bridge is in a horizontal arc.

The above-mentioned forces are illustrated in Fig. 4.4.3 and 4.4.4.

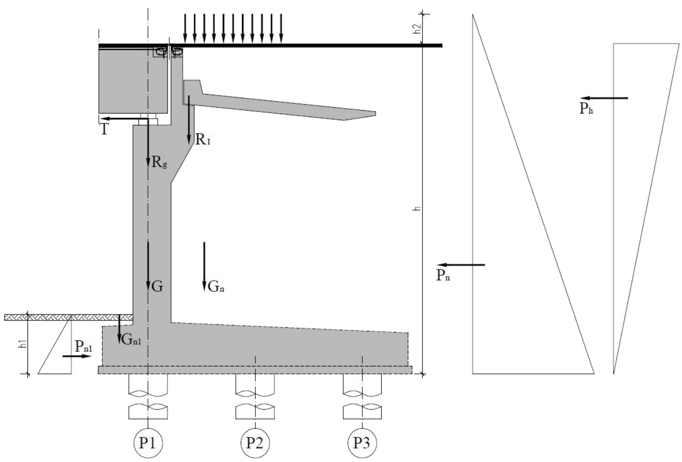


Figure 4.4.3. Forces acting on the abutment when the load is in a wedge faction *(by MJ)*

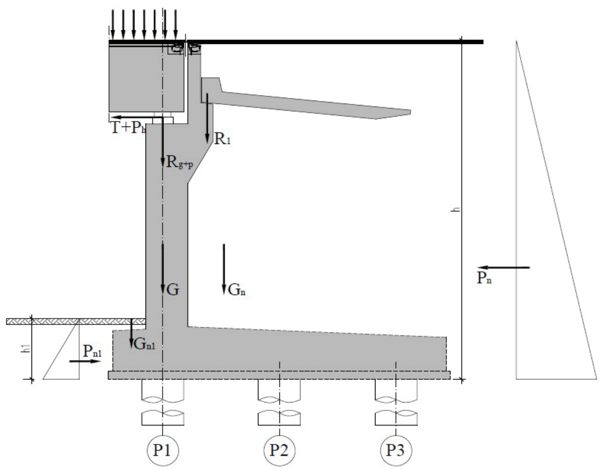


Figure 4.4.4. Forces acting on the abutment when the load is on span bridge *(by MJ)*

Each component of the abutment meets a role, eg. front wall of the abutment carries the load on the foundation and is an indispensable element to maintain the stability of the embankment. In fulfilling this function, helping wingwalls which can be divided, depending on their positions relative to the longitudinal axis of the object:

- perpendicular
- parallel,
- oblique.

Due to the nature of the merger with the body of abutment, the wingwalls can be divided into [Madaj, Wołowicki 2003]:

- hanging,
- standing,
- mixed construction.

The element at the end of the abutment body is cap beam, which carries the load transmitted by lower bossages. This is a very important element that needs to be well designed due to the high values of concentrated forces transmitted through the lower bossages. The abutments sunken above mentioned bench called top plate. Lower bossages as mentioned earlier transfer loads on the cap beam. They are designed as elevated upwardly to protect the bearings against moisture and dirt located on the cap beam.

Pebble wall is an element that protects bearings against their backfilling and creates space for the rest of the span of the bridge. This wall is also used as an element on which the transition board, which is an integral part at the junction of the road-bridge. Its mission is continual change of stiffness on the transition road from the embankment on the object.

### *4.4.2. Pillars*

Pillars are structures whose task is just like in the case of abutments, transfer loads of the bridge over the subsoil. Abutments and pillars are supports, with the difference that the pillars are intermediate support and abutments are extreme support. In order to preserve the aesthetic qualities of the pillars shall be designed according to the principle of the whole, ie. To be made as abutments, ie. the same material and the same technology. Due to the shape pillars can be divided into:

- massive stone or concrete,
- longwall concrete or reinforced concrete,
- in the form of columns topped strike girt,
- lightweight reinforced concrete columns topped girt or concentrated transversely,
- shapes letters V, M, T, W, X, Y transversely or along the object,
- shapes other than the above, if it follows the design and aesthetic needs.

Pillars of longwall usually its width covers the entire superstructure object. For aesthetic reasons, in some cases they are flush with the outer edge of the spar or the project behind the edge. They are also used tall, narrow pillars of the longwall, mostly in crossing the valleys. Fig. 4.4.5 and 4.4.6 visualized above described types of pillars.

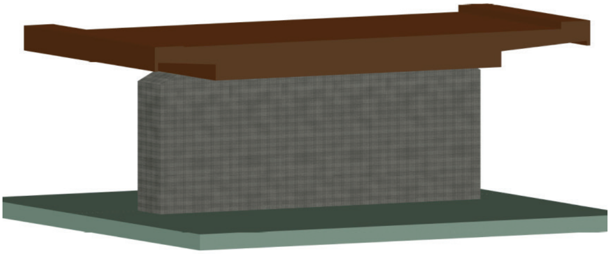

Figure 4.4.5. Protruding pillar *(by MJ)*

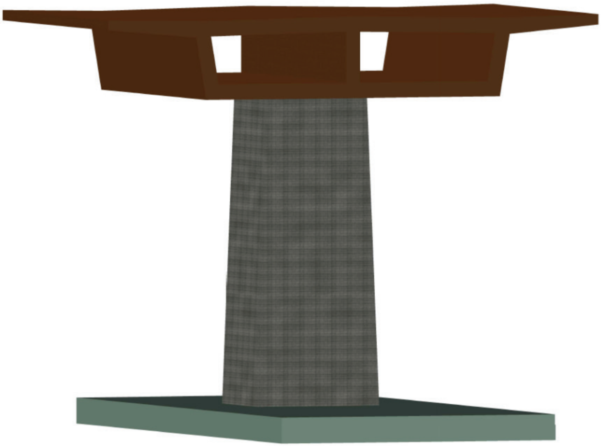

Figure 4.4.6. High narrow pillar of a bridge over the valley *(by MJ)*

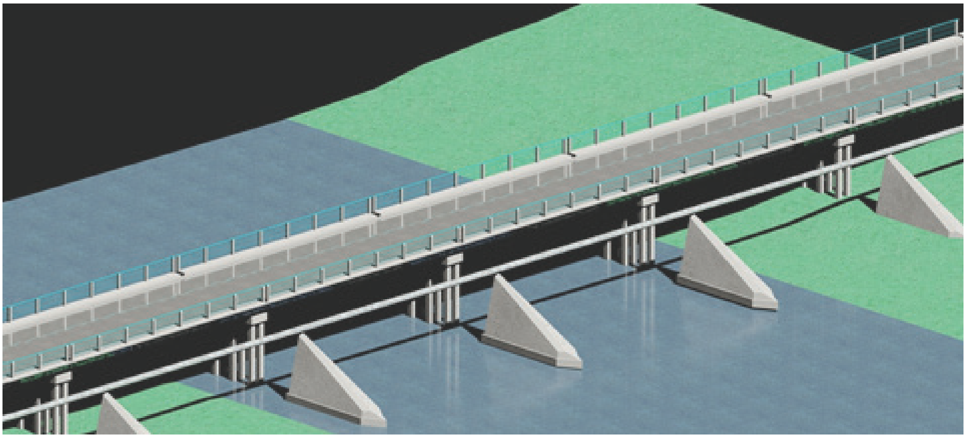

Figure 4.4.7. Starling visualization of the pillars of the bridge in Chlewiska (*by MJ*)

Due to the strong current of the river, pillars type of longwall are the best to use in such cases. Their weight and dimensions make it possible to move forces even from ship strikes. On navigable rivers pillars are protected by the so-called. starling, whose job is to break up ice floes, protection from bumps example. broken, flowing tree trunks or larger items. Example starling, which are separate protective structure pillars of the bridge shown in the fig. 4.4.7.

In addition, in order to reduce the effect of turbulence in the water around the pillars are used inclined edge of the pillar in the direction of the central axis of the bridge. In fig. 4.4.8. shows an example of longwall pillar representing the above description.

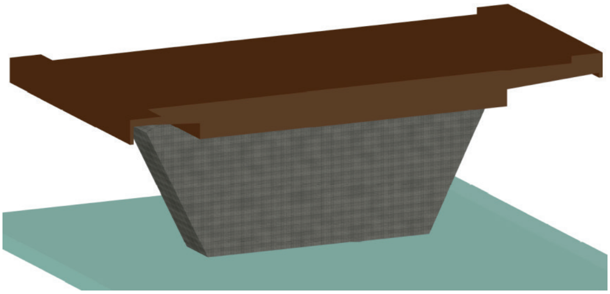

Figure 4.4.8. Pillar riverine with the front inclined towards the foundation *(by MJ)*

Pillars of the pole makes the effect of lighter compared to the longwall. They characterized by lower occupancy surface of the object, so they are often used in buildings located in urban areas and as pillars of flyovers and bridges access. They can take various shapes, for example:

- circular,
- oval,
- octagon,
- square with bevelled corners,
- rectangle,
- rectangle with beveled corners,
- hexagon.

The bridges erected in areas with large differences in terrain often used pillars with widened upper portions (in the form of a funnel – fig. 4.4.9). Due to the considerable size of box bodies are used cross-sections. Such widening, however, are a big hurdle for contractors who need to use special formwork. This also has an impact on the growth of investment costs.

a) b)

Figure 4.4.9. a-b) pillar expansion in the upper part, the bridge over Wisla River in Kamień *(by SLK)*

Bridges with spans of large width sited in areas with little difference in the terrain, often have so-called twin pillars – fig. 4.4.10.

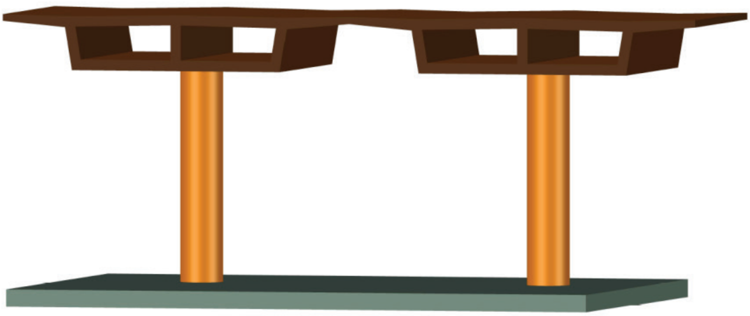

Figure 4.4.10. Twin pillars *(by MJ)*

Figure 4.4.11. Pillars of the V-shaped *(by MJ)*

It is worth mentioning that these pillars are equivalent to support the body in the shape of a cuboid with two rows of rubber bearings [Jaromniak 1981].

Due to the limitations terrain in urban areas are the most trusted pillars in the shape of a V. In terms of construction, this solution is appropriate when the body pillar is based on a compact plan sited foundation eg. On piles of large [Jaromniak 1981]. The following shows a 3D model of the abovementioned intermediate support.

On the intermediate supports work following forces:

- gravity of pillar (G),
- dead weight with accessories (Rg),
- reaction of payloads object (Rp),
- ice pressure (H),
- Impact fleet of river, road, rail,
- wind pressure (W1/2),
- braking force, acceleration (Ph),
- frictional forces in the bearings (T),
- earth pressure on foundation (GN),
- For the pillars of the river buoyancy of water (Ww),
- forces resulting from expansion form the pillars of the arches in the case of arch bridges.

The listed forces are illustrated in Figure 4.4.12.

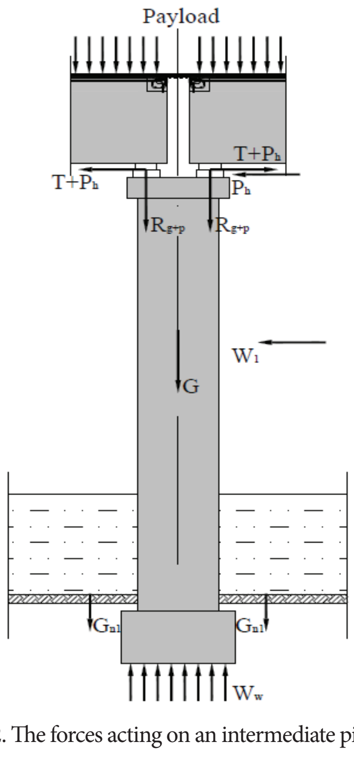

Figure 4.4.12. The forces acting on an intermediate pillar *(by MJ)*

### *4.4.3. Pylons*

Pylons are structures which are identified with the towers. Their height and shape cause interest among many people. From the standpoint of an engineer these are components acting as support in hanging and suspension bridges. By pendent them tendons (cables), carry all types of loads acting on the bridge. They can have different shapes and be made of different materials. Nowadays, more often designed so-called hybrid pylons. This means that the pylon is built of many materials simultaneously.

Frequently bottom of the pylon is made of concrete and the upper part of steel. At the stage of choosing the material for what is to be done each structure, the decisive factor is the economic aspect. Designer determines the used solutions at the stage of assumptions [Biliszczuk 2005]:

- material which is to be executed pylon,
- anchoring system want the pylon,
- method of communication vertical,
- types of installations that will be routed inside the pylon,
- the decision to include doorways or openings in the bottom of the pylon.

The system of anchoring shrouds in the pylon must be well-chosen, because in their presence, in the construction of the pylon created a very large forces that must be spread on neighboring branches of the tower. To that end, a number of ways of anchoring tendons in the pylon or carry them out to the other side.

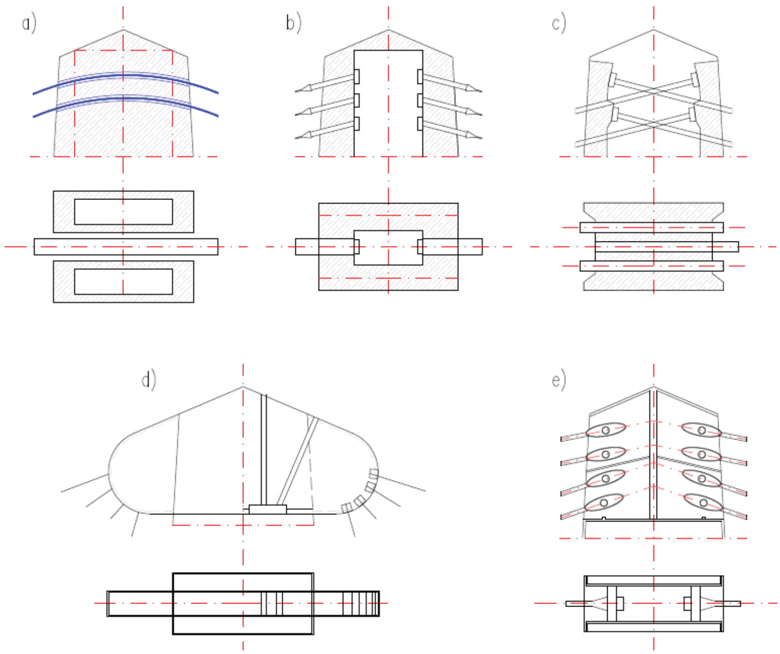


Figure 4.4.13. Different ways of attaching the suspension rods to the structure of the pylon *(by MJ)*

We can distinguish:

a) seat, ie. the steel tube mounted in a pylon, through which the tension member is passed. The minimum radius of curvature of the saddle is equal to 5 m. The disadvantage of this system is the possibility of corrosion and fatigue tendon and the necessity of a precise embodiment (Fig. 4.4.13 a),

b) a system of anchoring rods at the inner side of the pylon construction of the box "from the inside" (Fig. 4.4.13 b),

c) a system of anchoring rods on the opposite outer sides of the pylon (Fig. 4.4.13 c),

d) use of so-called. head that is mounted on top of the pylon. This solution is used for the radial want (Fig. 4.4.13 d),

e) system of anchoring rods articulated on the outer walls of the pylon (Fig. 4.4.13 e).

The main factors affecting the choice of the appropriate method of anchoring or back of legs on the pylon, are:

- cross-section of the pylon (construction),
- characteristics material of tendons,
- type of shroud layout.

If the connection shrouds with the pylon is articulated, it is recommended that shrouds were in the form of rods. When we apply the saddle, remember to tie rods are made of a material with a low flexural stiffness.

The pylons are made primarily from materials such as:

- steel,
- concrete.

***Steel pylons***

Steel pylons are often used in bridge, due to the speed and ease of installation. The construction is coming to the site in segments that are connected via screw connections or welded. Thanks to this pylon construction time is much shorter than the concrete pylons. Such pylons are made mostly of:

- steel pipes, which in some cases are filled with concrete,
- sheet steel reinforced longitudinal ribs and a cross member, made of sections open.

In the case of small bridges, the most footbridges, used steel pipes. In large buildings applies only box sections that are ribbed on the inside along and across the section. A perfect example is the pylon Solidarity Bridge in Plock.

The cross-section of the pylon has variable height along the axis of the bridge, ie. is wider at the place of mounting it in the span rather than at the top. Each pylon wall is reinforced with longitudinal ribs T-track section. Figure 4.4.14 shows a cross section through the pylon at the mounting and at the apex.

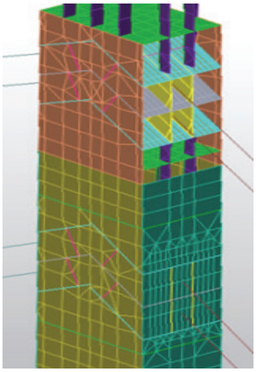

Figure 4.4.14. Section through the pylon of a bridge of Solidarity *(by MJ)*

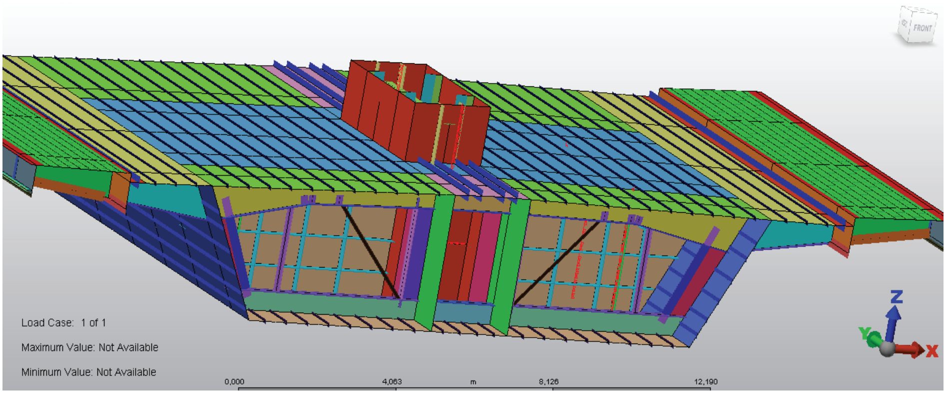


Figure 4.4.15. View of the connection the pylon of the span *(by MJ)*

There are many bridges that have steel pylons. It must be remembered that each project must be examined individually. Pylon may have a different shape, which directly has a large influence, eg. the forces transmitted from the suspension system, which will be different from the pylons of a similar shape. Solidarity's Bridge pylon has internal ribs so that the maximum thickness of the sheet metal used for the execution of 50 mm, where for comparison in the bridge in Podebrady sheet has a thickness of 80 mm.

***Concrete pylons***

At the design stage, the designer must decide how it will proceed the construction of the pylon, prefabricated or monolithic. The prefabricated elements should be not longer than 25 m, due to the difficulty in transport. Upon their arrival at the construction, these elements are combined to form a single structure. It is recommended that the suspension system was hitching to the pylon by anchoring tendons in opposite walls of the pylon.

In large bridges pylons are made of monolithic technology with the most box-sections. A method of anchoring shroud in these pylons can be as follows:

- Using the saddle,
- using a special core to which are attached the tendon,
- anchoring to the inner wall of the pylon,
- anchoring the opposite wall of the pylon.

Cross-sectional dimensions of the pylons of over 80 m should be a minimum of 3,00m x 6,00m. This is due to operational reasons and implementing major difficulties during the construction of such structures.

***Selection of the number of pylons***

One of the main aspects when choosing the amount of pylons, in addition to economics, is the amount that depends on the span length. The longer span, the higher must be the pylon. A very big impact on the selection of the number of pylons has also architectural aspect. The number of pylons of a hanging or suspended bridges affects many aspects such as:

- width of the obstacle (the main span length),
- terrain (eg. An island located in the middle of the river which is ideal for foundation pylon),
- architectural considerations,
- economy – construction costs,
- difficulty of execution.

The solution to the basic design consists of two pylons. Based on theoretical considerations [Biliszczuk 2005], it is concluded that the construction of the bridge using two pylons is about 40 % cheaper than a single pylon. It is obvious that in the case of the construction of the bridge on the spans suspended for one pylon, its design must be more massive, better, set on a greater foundation. Ropes forming the rigging system must be longer and heavier at the same time. Construction of the pylon involves higher costs arising from increased use of materials, manufacturing technique, installation and implementation of major mistakes. Such pylon is more strenuous, which means that it must be made of a material with higher strength, which is associated with higher costs. In conclusion, the height of the pylon is primarily due to cost analysis of its implementation. According to the paper [Biliszczuk 2005], the theoretical amount of the pylon above the deck in the case of two pylons, taking into account the cost of their construction should be at least 0.2 main span length, and in the case of building one of the pylon 0.4 main span length. In the book [Jaromniak 2002] we meet with pylons approximated height values in relation to span length, which are respectively:

- 0.2–0.22 of the main span length, in the case of two pylons H-shaped,
- 0.22–0.25 span length of the main in the two pylons shaped A and the inverted Y and V,
- 0.36–0.396 span length of the main, for one pylon in the shape of an H,
- 0.396–0.45 of the main span length, for one pylon in the shape of the letter A and the inverted Y and V.

In terms of architecture, the shape of the pylons is very important, because it depends on the aesthetics of the entire bridge. Factors affecting for a shape of the pylon include [Jaromniak 2002]:

- width of the bridge,
- span of suspended span,
- height of the pylon,
- clear height under the bridge,
- means of securing the suspension (in one plane or two),
- type of suspension system (ie. Whether it is a type of fir, harp, etc.)
- method of attaching the pylon suspension.

Due to the form of the pylon distinguish six basic groups:

- trapezoidal, ie. Pylons H-shaped or π, used for fixing the suspension in two planes,
- triangular, ie. pylons A shaped or inverted Y,
- deltoid,
- free-standing,
- combined,
- repeated.

Examples of completed bridges pylon shapes mentioned above is shown in Fig. 4.4.16 to 4.4.21.

Figure 4.4.16. Rędziński Bridge – pylon trapezoidal [96]

[96] http://mklr.pl/222573

Figure 4.4.17. Pont de Normandie bridge – pylon triangular [97]

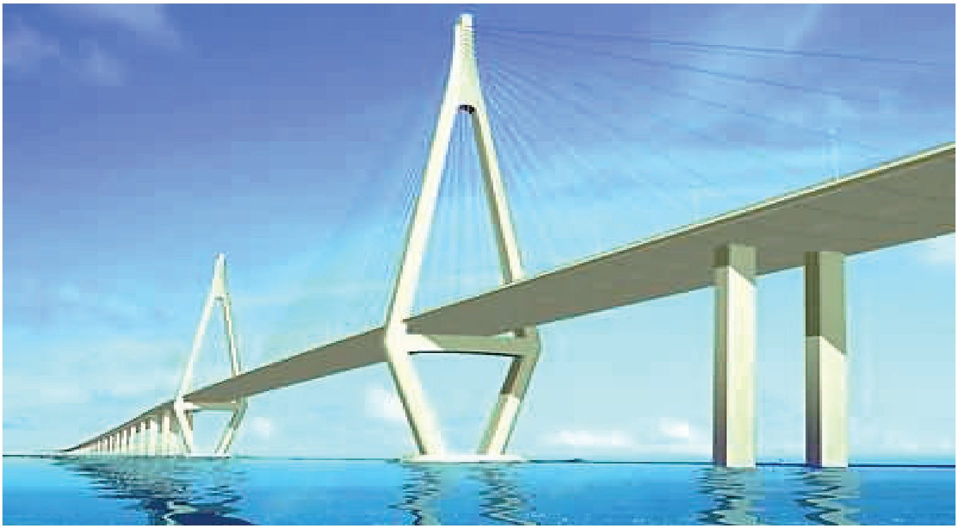

Figure 4.4.18. Deltoid pylon [98]

[97] http://photorator.com/photo/24317/the-pont-de-normandie-is-a-cable-stayed-road-bridge-that-spans-the-river-seine-linking-le-h-maupetit

[98] http://engineerstoday.blogspot.com/2008/12/what-are-basic-types-bridge.html

Figure 4.4.19. Free-standing pylon [99]

Figure 4.4.20. Rio–Antirio Bridge - combined pylon [100]

[99] https://en.wikipedia.org/wiki/Cable-stayed_bridge

[100] https://pl.pinterest.com/ysnehoray/beautiful-bridges/


Figure 4.4.21. Fred Hartman Bridge – multiple pylon [101]

In shaping the pylon it is important to tilt arms (legs) of pylon. If the arms are directed to the center of the pylon, in the foundation created compressive forces, and for directing outward tensile forces. The directions of axial forces in the pylon and the foundation shown in fig. 4.4.22 [Biliszczuk 2005].

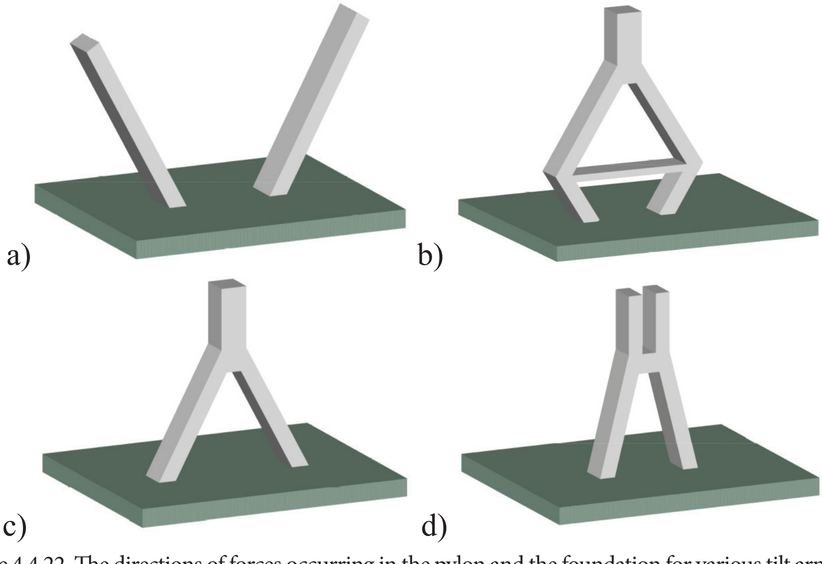


Figure 4.4.22. The directions of forces occurring in the pylon and the foundation for various tilt arms legs of a pylon.

[101] http://stevehopson.photoshelter.com/image/I0000G0g3btK8AqQ

Figure 4.4.23. Articulating mounting in the foundation *(by MJ)*

Pylon can be mounted in the main girder, eg. as in Solidarity Bridge in Plock, mounted in the foundation, eg. in Redzinski Bridge in Wroclaw or articulated to platform or foundation. Example pivoting the pylon to the foundation shown in fig. 4.4.23.

Restraint pylon in superstructure is present in most cases in the box girders. This obliges the local strengthening of the girder and to the use of support bearings with high capacity. The disadvantage is the formation of very large bending moments at the pylon. In the case of restraint pylon in the foundation, we get the effect of increasing the rigidity of the whole system. Unfortunately, even in this case, there are large values of bending moments. Linkage means brings more benefit, namely:

- reduction of bending moments in the girder main,
- reduction of bending moments in the foundation,
- static analysis system is easier.

The disadvantage of the pivoting pylon is the difficulty of execution and higher investment costs. Due to the size of the section of the pylon and the ratio of the bending stiffness of the pylon to the main span, we distinguish pylons usceptible and stiff.

In general bridge structures, depending on their function, size, type of structure and the type of road within which is situated, may or should include the following elements, which facilitate availability and usability:

- sidewalks,
- cycle paths,
- slope steps,
- ramps.

Moreover, availability of bridges may be considered not only in relation to people but also to animals. The structures for animals (ecoducts, landscape bridges) should be located in such places where the human activity is close to none or non-existent, at least a few hundred metres from the boundaries of the places of human activity. It is good to locate bridges for animals in excavations, which makes it easier to fulfil the condition of acceptable surface inclination. Depending on the country the rules governing location, construction and structure of bridges for animals are slightly different. In many countries (e.g. Canada, USA, some European countries) the design, implementation and maintenance of bridge structures within road systems is connected with pre and post implementation monitoring of biotopes dynamics, which facilitates considerably preparation of guidelines. In Canada detailed, long term research programmes are carried out which focus on the migration of animals, in particular within protected areas (e.g. Banff National Park) [Clevenger and others, 2002]. The principles of building bridges for animals in various countries were discussed in detail in the book entitled Bridges and ecological transitions.

The parameters of elements used in bridge structures which facilitate availability and usability of such structures will be different depending on many factors, including the country in which a given structure is located, who is to be the user of such a structure, the category of road within which the structure is situated, the size of structure, over what obstacle it is placed etc. Therefore, we should always look for the principles of construction in relevant guidelines or legal.

## 4.5. Mechanical aspects of aesthetical design of bridges *(SLK)*

The aesthetics of the twenty-first century is based on the search for expressive forms and new forms of expression, which reflect on the human imagination. On the other hand, it seems that the industrial era is ending and the world is entering into a new era based on computers, the Internet, with the excess of information. Thanks to the possibilities of the modern age, one can create a proper form in accordance to their imagination. This form may not be correct from a service or strength or even economic standpoint. The modern man rejects forms of logics introducing deconstructionism as a reaction to the structural body linearity which results from the fascination with high-tech achievements. Also bridge engineering often departs from the twentieth century design solutions. The attention is drawn to new solutions improving the strength of materials, as well as new forms which are replacing the known patterns. However, this approach also often causes nostalgic returns to the tradition of bridge engineering.

When one wants to design a bridge, they should conduct an initial study of its shape and proportions and even the colouring in accordance to the surrounding. In the Fig. 4.5.1. the simplified study is shown.

In the Fig. 4.5.1. the beam or plate carrying-deck is supported in abutments and on 2 intermediate pillars.

In the case a) 3 independent simple beams are used. Visually, it is a very clean and open scheme, simply nice. For a case of unifmly didtributed load, the material effort of each beam element is the same, however mechanically not optimal.

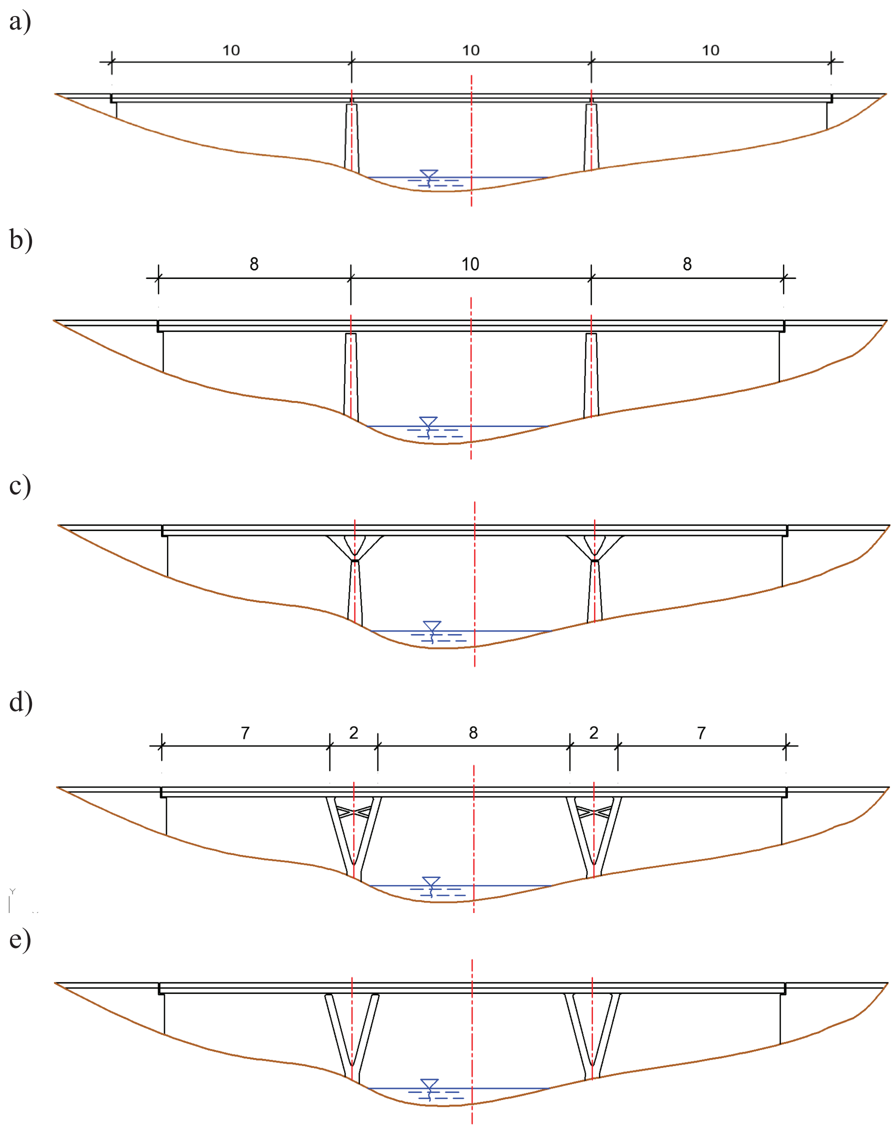


Figure 4.5.1. Study of 3 span bridge a) 3 simple span beams b) continuous beam c) caddles on verticals d) cdditional bracing in V pillars e) V shape of pillars only

In b) option the extreme spans are shorter than those intermediate by approx. 20%. This is an effect of a continuous beam which is used here. The static material effort is equal in spans as well as in over-pillar regions. The both cases, a) and b), have very similar view, especially because the same form of verticals and pillars is assumed. But in the mechanical and economical sense the case b) is proper. The c) version is a connection between the vertical and V pillar. It is still the continuous beam but the supporting sector on the pillar is extended due to 3 cases. Firstly, the span sectors are shorter. Secondly, in the over-pillar beam part the bending is reduced. Thirdly, aesthetically it is richer than a–b cases. In the cases of d) and e) the statics is the same; however, the bridge view is different. In d) variant the last word has been said while if analysing d) then the simplicity of the support is simply perfect.

Let it now be carried out a short analysis of bending moment distributions and their values in two cases of a symmetric 5 aisles frame static schemes.

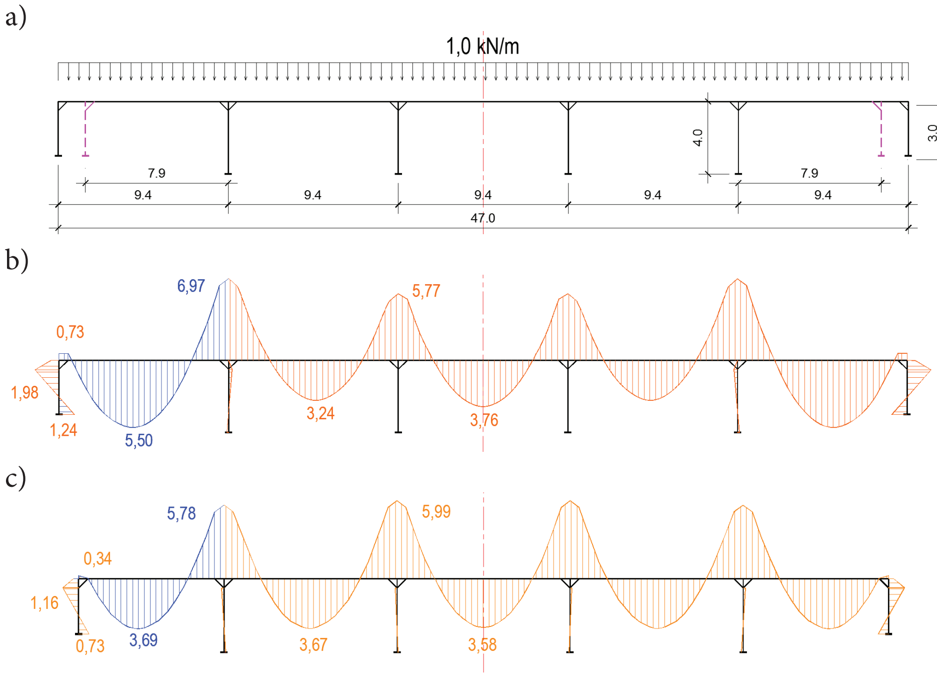


Figure 4.5.2. The frame static scheme of the first Lutoslawski bridge in Lublin a) Load – [kN/m] and geometry [m] b) Bending moments for existing bridge scheme, [kNm] c) Frame with reduced extreme span lengths, bending moments [kNm]

The proportions of the span are relevant to the cases a) and b) in Fig. 4.5.2. This is a qualitative analysis of a real historical RC bridge which is in the city of Lublin and was built in 1908. Bearing in mind that those days saw the beginnings of structural mechanics, it is clear that the static scheme is not optimal. Assuming the uniform load distribution of a value at 1 kN/m action on the frame transom, Fig. 4.5.2.a, the bending moment graphs were found, Fig. 4.5.2.b. At the same time Fig. 4.5.2.c shows graphs of the bending moments if the extreme frame spans are reduced in length. This case is considered to be optimal. The obtained bending moment values allowed us to formulate the following measures of frames mechanical adequateness

- in extreme span we have

$$\Delta_s = \frac{55,0}{36,9} \approx 1,49 \tag{10}$$

this means that the material overload amounts to 49%;

- in the over the pillar tension zone

$$\Delta_p = \frac{69,7}{57,8} \approx 1,21 \tag{11}$$

here the overcharge is of 21%.

These simple calculations show the influence of the static scheme on the further ultimate and serviceability limit states results. Statics and dynamics are no less important than aesthetics and it may be the other way around as well.

Continuing the case of the First Lutoslawski Bridge in Lublin, let us now consider the aesthetics problem. In the Fig. 4.5.3. its view is presented.

Figure 4.5.3. The First Lutoslawski Bridge in Lublin, 1908

Indolence, ignorance, the lack of imagination of diverse social groups of the Lublin city have contributed to the fact that this unique monument reached the ultimate limit state and faces a collapse of its structure. Nevertheless, the hope goes out last. That is why many engineers of bridges continue to make efforts in order to save this bridge. One of these activities is the constant propagation of knowledge about bridges from the early period of reinforced concrete and the preparation of various options that would have potentially be applied when the designing of the bridge renovation will occur.

The view of the bridge is not interesting. Grey concrete, poor elevation, visible negligence, mediocrity – these words appropriately describe the current state of the bridge. Almost no-one remembers that the entrance to the bridge was underlined by four corner columns decorated with lamps lighting. On the other hand, this bridge is about pure mechanics, which was already partly covered above. However, one can always take advantage of even the slightest chance that the image of the bridge be emphasized by the use of these modest architectural elements, which in some sense are dormant. In the

According to the bridge project a gentle emphasis of supports was made which here is called pilastring, see Fig. 4.5.4. Thinking of the future bridge view, two options are possible. Both are derived from the use of low contrast of grey paint appropriate to the view of concrete.

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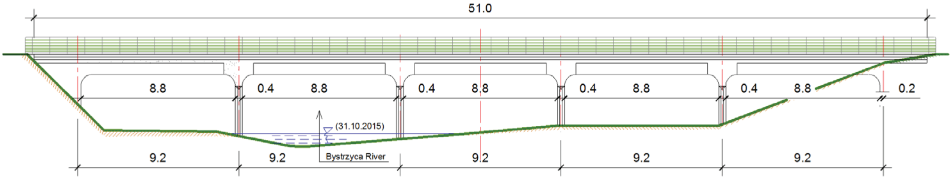
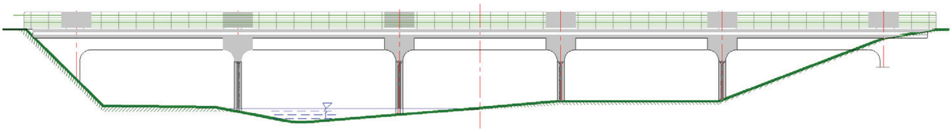
Fig. 4.5.4. the *pilastring* as well as balustrade are analysed in such aesthetical task.

a)




b)



c)

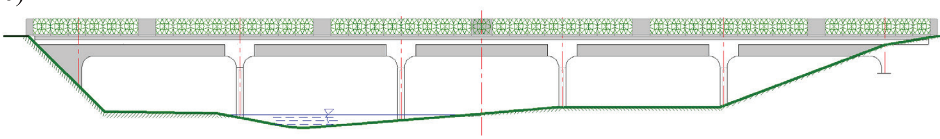


Figure 4.5.4. Possible revitalizing actions of the First Lutoslawski Bridge a) current view b) pilastring c) anti-pilastring

In the Fig. 4.5.4.b the pillars are not only darker than the beam but they are also heightened by locally adding grey barrier shields.

The second option is the opposite of the one above and this is why it is called anti-pilastring. Here, the supports are clear, while the side surface of the beam is stronger in colour. The same is applied to the darker barrier subfields to strengthen the beam views.

Incidentally various proposals of barriers for pedestrians are introduced. The first one – parallel horizontal bars – corresponds more or less to the original barrier. The second one is a little richer. The elliptical arrangement is crossed by a diagonal cross. The repeatable basic barrier element acts as a sort of floral ornament. In this case, to decide the superiority of one proposal over the other the estimation is a like zero/one selection problem, isn't it ?

## 4.6. Aesthetic reflection about the 2nd Lutoslawski Bridge in Lublin *(SLK)*

Let us discuss the second historical RC[102] bridge located in Lublin. It was built in 1909 in the Hennebique technology by Polish engineer Marian Lutoslawski [Karas, 2014][103].

[102] RC – reinforced concrete

[103] see also the monograph Marian Lutoslawski Bridges in Lublin, which is written in Polish language but has the extended, 15 pages, Summary in English.

After the renovation in 2011, it now serves as a footbridge. It is worth mentioning that many cultural events took place there. The bridge has an informal but reasoned name *the Bridge of Culture*.

a)

b)

Figure 4.6.1. *Marian Lutoslawski Bridge* or *the Bridge of Culture* in Lublin a) An approach to the bridge with the neo-gothic balustrade visible b) Footbridge for pedestrians and cyclists as well as for city events

Just next to the bridge there is a crossroad with traffic lights. Short time when one waits for the green light is enough to take a glance on the bridge. In these circumstances all possible forms of observation are used, Fig. 4.6.1.a–b.

In both photos, the viewer's eye is attracted to the decorative openwork balustrade. This is the recorded image for tourists and architects. Is impressive, especially because of its repeatable gothic window bay in the balustrade. In addition, it constitutes the context for the architectural image of *Cathedral Square* redesigned by Antonio Corazzi, some years earlier. The beginning of the bridge is marked by corner column lamps, neo-gothic as well. The form automatically stands out from the unengaging municipal surroundings. The balustrade was a demonstration of Lublin Magistrate officials' pride and ambitions as compared to other neighbouring cities such as Lvov, Cracow or maybe even Paris or Vienna. We must honestly admit that the idea was 100% successful. The city gained a bridge worthy of palaces and aristocratic residences. Apart from its aesthetics the balustrade is simply nice, whatever it means, see Fig. 4.6.2.a. Due to the mentioned reasons, for architects the balustrade constitutes the whole bridge. This is an example of a narrow professional perception. In the discussed case it is justifiable but this is not a complete aesthetic analysis.

a)

b)

Figure 4.6.2. Lutoslawski Bridge in Lublin a) A side view b) Piles, columns and angle struts of intermediate pillars (by Monika Chmielewska)

When looking closer one should stress that the balustrade was made in a modern way, possibly with RC technologies. The basic openwork element was prefabricated. Only the face (directed to pavement users) of the balustrade has a spatial form. Its back is flat. Prefabricates were immersed into concrete mortar and after concrete hardening into a monolithic structure. At this we arrive at the field evaluations of civil engineers. Here, the architectural expression is supplemented by elements of aesthetics that are related to the quality of the technical concept and design, mechanics of bridges, quality workmanship and innovations. Certainly, this perception is more difficult compared to the architectural one. It requires more specialized knowledge and is quite difficult to study. However, one needs to remember that in general the architectural knowlage is more common.

Perceiving a bridge from the engineering point of view one sees foundations, a proper water clearance gauge, abutments, pillars, a carrying-deck and also facilities including balustrades. Somebody could object that these things have nothing to do with aesthetics. However, a bridge achieves the purpose of mechanical design, one or the other form of technical perfection, invoking the same strong impressions that accompany watching the Vermeer's *Lacemaker* in Louvre. Here, it was assumed that the beauty of a painting is equal to the beauty of the mechanics and structures of bridge.

A further explanation of the introduced engineering aesthetics leads us to Fig. 4.6.2.b. At the first glance one could say – chaos. Yes, but let us try to sort out and call the support elements. The verticals consist of two different elements. From the water mirror, approximately up to the horizontal bar the upper parts of so-called *Hennebique driven piles*[104] are visible. Due to RC technology the pile heads were monolithically joined with a cross bar and columns. A small eccentricity between piles and columns is visible, but this imperfection does not influence the whole framework, it is negligible, see [Karas, 2013].

The node between a column and a girder is expanded so as to transfer the increased bending moments in these areas. Girders with perpendicular cross-bars and concrete plate form an orthotropic palate. The first full theoretical analysis and practical suggestions for a potential application of the orthotropic plate was given by M. T. Huber in his monograph [Huber, 1914; Huber, 1929]. This type of deck is still under research with regard to steel, concrete and composite materials.

Figure 4.6.3. The bottom view on the orthotropic deck and an orderly image of pillars

Upon discovering the Hennebique RC technology the following theorem was formulated and proved [Karaś, 2014]:

> *The type of RC Lublin bridges were the successful transformation of wooden beam bridges technology onto new material i.e. reinforced concrete which at that time was an innovative proposal.*

[104] F. Hennebique was the inventor of this sort of piles.

Now, having all the technical data one can talk about precise mechanics instead of *chaos*. Moreover, a point of observation is important. In Fig. 4.6.3 regular constructional elements are legible and additionally the perspective is very close to the one in AutoCad drawings. The classical perspective invokes a relaxed and aesthetic impression.

Two points of views, i.e. architectural and engineering ones, were discussed. Now it is time to look at them together. Let us look at Fig. 4.6.2.a. The harmony, almost natural coexistence, and non-aggressiveness are the characteristics of this composition. After searching of one of the two only points from which such take is possible, the photography was made. The only two case i.e. two very special positions. In general, one can meet one of others. "Others" here mean the majority. In such circumstances, it is necessary to focus on an average bridge view as the one in Fig. 4.6.2.b. As it is, we have a case of a total failure of the idea of congruence, coexistence, etc. Once again, we have a chaos of verticals and angled bars contradicting the regularity and rhythms of the balustrade.

Heedless of such aesthetic divagations, the residents of Lublin accept the bridge and use it after its renewal. After years of deterioration, the bridge has risen again, like a phoenix, out of nothingness, both regarding its technical state as well as its image.

## 4.7. Arc as the carrying element and its exposition *(SLK)*

Figure 4.7.1. The rainbow between buildings of Lublin Polytechnic *(by SLK)*

This essay is different from many other divagations on arch bridges. It is very subjective and could be false in general or in parts. On the other hand it shows a possible way of the development of arch bridges through millennia. An arc is a natural shape observed by humans just from their beginnings. It is a rainbow. Throughout the time it has always impressed people, regardless of a historical period or a person's age Fig. 4.7.1. Without question it is a very emotional and synergic image. Probably because of its naturalness, similar however different enjoyment is brought about by watching arch bridges. It is not by mistake that arch bridges aesthetically dominate over other bridge shapes. The arch has a very important technical advantage. It is possible to construct a bridge arc so that the main element is in a dominated compressive state, with negligibly few remaining internal forces. This was the reason for building hundreds or even thousands ancient bridges erected mainly as road bridges or aqueducts. The common availability of stone and brick contributed to an extensive construction of arched bridges in the Roman and Byzantine Empires. There is an arch bridge in Diyarbakir (south-eastern Turkey) which can come from the period of the Persian Empire, therefore, it may be even older. It is obvious that brick and stone elements have always been perfect for compression, significantly weaker for tension and shearing. The same potent image gives a single arch span as a string of arcade arches. Harmony, symmetry, and a paradoxically dominant feature viewed up closely and from the distance, with any material are characteristic of an arch bridge design. Bearing in mind the history of arch bridges, we can talk about outstanding structures, which, in a sense, again discovered opportunities of arch shape. Most often, these *turning points* were associated with the emergence of new materials and technologies.

The oldest known bridges in the world still serve as tourist footbridges in Peloponnese, near Arkadiko village. Precise dating is not possible, but their estimated age is no less than 3 millennia – the Mycenaean bronze period. Actually, they were rather bracket bridges. However, after many earthquakes which smashed originally marble plates into smaller stone blocks, we can talk of a primitive arch as the main structure, see Fig. 4.7.2., [Drogi i mosty Karas, Kowal].

a)  b) 

Figure 4.7.2. The Mycenaean Bridge *B* made with a marble blocks a) inlet b) outlet *(by SLK)*

Probably, the bridges are not nice but especially this, mentioned above, mechanical nature of the structure as well as a historiosophical reflection make the greatest impression when one walks on the bridge.

The next two photos, Fig. 4.7.3., show very elegant and pedantically constructed historical stone bridges which are still in use.

a)  b) 

Figure 4.7.3. The Euphrates Valley at the foot of Mount Nemrut near Cendere (Turkey) a) Severan Bridge (Septimius Severus) over Chabinas Creek, (193–211 AD) b) Devil Bridge – no information *(by SLK)*

The Severan Bridge, Fig. 4.7.3.a, had a leading position in the championship for achieving the longest span. Probably it was the second largest extant arch bridge constructed by the Romans. It is 120 m long and 7 m wide. Apart from the perfect geometry, it is worth mentioning that it was located in the narrowest part of the river, so one span – one bridge. The trimmed and grouted stone blocks are different in shape but an average side dimensions are 90x60 cm, in front 60 cm. The extended abutments are immersed in the natural rocks at the end of the mountain canyon. After the new bridge (in the background) was commissioned in the 1950s, the Severan Bridge was closed for road traffic and now it is only a monument testifying to the Roman engineers' professionalism. The bridge was built by four Commagenean cities.

The second bridge is unofficially known as *the Devil Bridge,* but in Turkey practically every red bridge has the same name. The bridge is placed on a secondary road, actually a rural one. The road pavement is residual. It was suspected that the residuals could be original i.e. from Roman times.

The arch is the strongest element of an arch bridge. It is visible in Fig. 4.7.3.b that sidewalls were rebuilt. Nowadays the road pavement has the form of a thin (12cm) RC plate. Mountain rivers are characterized by rapid variability of water levels, mainly as a result of heavy rains. To avoid the damming effect of the river water, auxiliary flow openings were used, usually with less light than the main span, as in Fig. 4.7.3.b.

Here the geometrical aesthetic of the double parabolic arch (by locals also called the Arabic arch) is disturbed as a result of the contact with the crude mountain nature where the only sound was the noise of swollen river water. The discussed bridge could be used as an example of the *sustainable development* concept.

The Miraculous Aqueduct in Mérida (*Emerita Augusta* in ancient times), Spain, is worth its name. Now only ca. 850m m ruin, it was a part of ca. 5km long structure. Now there are 38 arched standing pillars of 25m height in line. The columns were braced by firebrick arches on 3 levels. Arches are acting as battens between the rigid columns. Having in mind that the main load is the dead weight, it should be considered that such rigidity in colonnade plane is sufficient. Today it is obvious as it has been proven by its durability over a very long time.

a)  b) 

Figure 4.7.4. The Acueducto de los Milagros, 1st c. AD a) Semi-longitudinal view b) Brick arch stiffener clamped to the column of one buttress *(by SLK)*

An aqueduct in the Roman times was a 100% utility object, with reservation we can say – an industrial one. But its view evokes strong emotions. Actually, it is very difficult to describe their nature, and, of course, they are very individual and private. Depicting it is also not easy because of multi-level possible approaches. The whole image is too large to be embraced at a glance, otherwise, it would not be so interesting. A closer view is friendlier. Its colours become important, they address the viewer – they are pleasant. Sandy-grey granite is animated by regular, gentle, horizontal stripes of red bricks. When you go back a few steps, the columns become visible in their entirety and the red colour underscores begin to meet the arc bracing on equal levels. At the same time rectangular classical windows were built. Again, just a few steps back, and we have an expanded image of a destroyed cathedral without stained glass windows. This probably has the strongest impact. The same elation accompanies when a choir sing Haendel's Messiah. The aesthetic impression evoked by Acueducto de los Milagros is also the secret shared by the wet green meadow surrounding the arcade.

At the same time, in Segovia was built an equally famous Roman aqueduct. There, the whole structure was made of ashlar granite. Segovia's *Devil Acueducto* is beautiful but not as joyful as the *Milagros*.

Comparing to the Segovia aqueduct the *Milagros* construction discussed here is more advanced and complex. The main pillar/column consists of 2 outer walls made by ashlar granite stones. Between the walls, Fig. 4.7.5.a, were filled with Roman concrete (opus caementicum) [105] with crushed stones of the average diameter from 10cm to 30cm, Fig. 4.7.4.b. In the other perpendicular direction were built buttresses of ahlar granite on both sides. However, the link between the walls and the buttresses was not strong enough. As a result, the most of the buttresses separated from the columns. Only ca. 20% of all columns have kept the original shape. Hydraulically, the aqueduct is a simple one. This means one level of open watercourse with a minimal longitudinal slope, ~0,03 (3%).

[105] see: latin – caemente, puzzolana

a)  b) 

Figure 4.7.5. The Acueducto de los Milagros a) frontal view b) buttress lack *(by SLK)*

a)  b) 

Figure 4.7.6. Siphon aqueduct in Aspendos a) longitudinal view b) a tower, *(by SLK)*

Here we can recall that in the ancient Greco-Roman city of Aspendos, present – day Turkey, during the Roman period a (inverted siphon) siphon aqueduct was build which was twice lower in the main sector (15m) while boasting a similar length. But at its ends two 40-metre towers lift down and up the watercourse, Fig. 4.7.6. The Aspendos aqueduct had the form of a tight tube, 60 cm wide and 90 cm high. However, the Aspendos aqueduct was built 200 years later.

How did they know the Pascal's Principle? But they actually did.Concluding, the perfect form combined with usefulness of a bridge is possible only when the construction is perfectly designed and executed. Until the Industrial Revolution, bridges were built with wood and stone. The progress in the construction of stone bridges was insignificant. But at the same time many beautiful objects were created, lasting to this day. As an example may serve the stone bridge over the river Tajo which is an element of the fortifications of Toledo, Spain.

One of the biggest advantages of an arch bridge from the point of view of aesthetics is its reflection in the river water. Geometrically, the reflection is a mapping in the Euclidean space. We can create a reflection by axis or plane. This produces a doubling of an image. In the case of arch bridges a richer space is created. Together the arch and its reflection in water complete the picture by a closed axially symmetric aesthetic impression by triggering the associations with the regular closed regions as an ellipse or even a circle, Fig. 4.7.7. Also, we can think of lens or an eye. By the way, the ancient bridge in Diyarbakir is known as *the Ten Eye Bridge.*

Figure 4.7.7. Gothic *Puente de* Alcántara over Tajo River in Toledo, XIII c. *(by SLK)*

In the photo above crude Gothic fortifications and the bridge meet a cruder rocky nature. The *ellipses* are in a visible contrast to the crude stone landscape.

A new deal for bridges was the period of the industrial revolution in England. This period favoured beautifully designed and crafted wrought iron – the *Ironbridge* in Coalbrookdale. The bridge was restored and adapted to the needs of museums and tourism, Fig. 4.7.7. In those years, forged steel was a new construction material. Today, the rods dimensioning is not known. Probably the design methods were based on the blacksmithing knowledge. The bridge delights with its delicacy and the obviousness of forming knots. The contemporary space arrangement of the museum area promotes family tourism.

Figure 4.7.8. Ironbridge Birthplace of Industry, built in 1779–1781, over the River Severn (*photo by curtsey of Ironbridge Museum*)

The bridge eye is romantic and funny, isn't it ?

The way from wrought iron to steel was long. The symbol of Paris – the Eiffel Tower was made of iron. Gustave Eiffel and his associates built bridges as beautiful as the Paris tower. Fig. 4.7.9. shows an iron bridge in Porto which was designed by Théophile Seyrig, an engineer educated at Eiffel's technical office. It is a tied-arch bridge. This means that the horizontal reaction – *thrust* – in the arc headboard is taken over by a tie in the bottom.

Figure 4.7.9. *Ponte Dom Luís I* over the Douro River in Porto, by T. Seyrig, 1886 *(by SLK)*

The main elements i.e. the arch, the beam carrying-deck and a tie were made as trusses of iron rods connected by rivets. There are two transportation decks. The upper deck carries the traffic straight into the old city of Porto. The other, the bottom one, is situated on the tie truss and directs vehicles to the port quayside. It is worth mentioning that the arc has also an additional role. The pillars standing on the arch support the upper carrying-deck while the suspending ties are attached to the arch at the same points as pillars are located. It the front there are barges with Porto vino barrels waiting to go on a voyage to London, as one can presume.

An invention of the Portland cement was a turning point in the RC technology. Many names should be recalled, but, in short, it is assumed that the farther of this binder was Joseph Aspdin, 1824. The first bridge made with RC was built in the Chazelet garden by gardener Joseph Monier, 1875. Also – briefly – the engineers who in these days built hundreds of bridges were F. Hennebique and G. Wayss. Having in mind our subject – the bridge aesthetics – here I would like to present a small, maybe even unimportant, park bridge designed by a Polish professor of bridge mechanics, Maximilian Thullie, in Lvov, in 1894.

Currently, it is not possible to design a footbridge that is visible in the picture. There are not railings, a very clear elastic deflection can be felt, even with the passage of several people, contribute to the fact that the criteria set out in EN 1992-1 as ULS and SLS are not met and, above all, the safety conditions are not fulfilled.

Figure 4.7.10. The Thullie footbridge in Lvov *(by SLK)*

The photograph was taken in spring, early in the morning. In the background, we have Lviv's Art Nouveau buildings, and the bridge is as delicate as a curve drawn by an architect's hand. It is a bow, a fragment of a shallow parabolic arch, which was trimmed at bedhead. The same arch bridge was used by Salvador Dali in his painting *The Broken Bridge and The Dream* [106]. The delicate dreams in Dalí's image are ephemeral and translucent, similar to Botticelli's Primavera. They could be staged as a play in a theatre of the Thullie footbridge. The bridge participates in the Lviv Politechnic student's life: every student begins and ends their studies by crossing this footbridge.

In the first half of the twentieth century, a strong imprint on the design and aesthetics of the bridge was left by Robert Maillart. His structures went beyond counting skills used at the time as calculation methods. His bridges, in the technical sense, are arched shield structures coupled with flat shields and plates. As a result of his engineering operations the mountain landscapes of Switzerland have been enriched with concrete/RC, non-traditional bridges, often referring to Cubism.

The Sidney Harbour Bridge represents steel bridges here. The Bridge was rather conservatively designed [R. Freeman, L. Ennis, E. Judge], but its arch beautifully spans the harbour entrance. The works were carried out for eight years – the bridge was commissioned in 1932. This bridge was a symbol of optimism, because it was a signal of recovering from the global financial crisis. Corrosion protection of the bridge was carried out by covering it with grey paint, because those days it was the cheapest technique. The bridge carries a considerable traffic capacity. Eight lanes for vehicle and two tram lines serve for traffic. The tram tracks were converted for road traffic in 1950s [107]. The arch characteristic ratio is

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[106] El puente roto y el sueño, The Salvador Dalí Museum (Reynolds Morse Colection), St Petersburg, Fl, USA, available at: http://www.salvador-dali.org/cataleg_raonat/fitxa_imprimir.php?obra=601&lang=en, approach: 22.10.2015.

[107] http://www.australia.gov.au/about-australia/australian-story/sydney-harbour-bridge, [25.11.2015]

$$\frac{f}{L} = \frac{134m}{503m} \approx \frac{1}{3,75} \tag{12}$$

The bridge width is 49 m as well as the clearance for shipping. The total length amounts to 1149 m.

Watching the bridge, the bridge structure itself, from the point of view of aesthetics, the impression is mediocre, at best. However, one should keep in mind that this is also the gateway to the port of Sidney; the bridge became a gate and a symbol of the city. It is immediately associated with Sidney as Eiffel Tower is with Paris, Fig. 4.7.11.a.

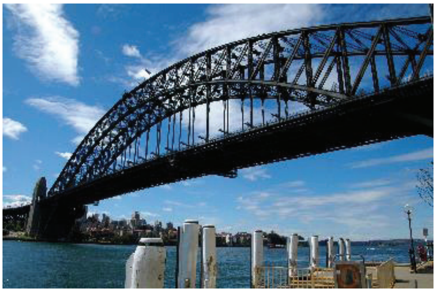
a)  b) 

Figure 4.7.11. Sidney Harbour Bridge a) The truss arch b) Coincidence of two Sydney symbols (*by prof. Jacek Czarnigowski*)

Nevertheless, it is not all. Right next to the bridge there are sails of the Opera House in Sydney (architect: Jørn Utzon, 1973). There is a case of coincidence between the two very strong dominant features which interestingly complete each other, Fig. 4.7.11.b.

Fig. 4.7.12. presents the modern steel arch bridge in Ostrołęka. Ostrołęka is located in central Poland and the bridge is over the Narew River. The structure was designed by Marek Łagoda and erected in 1994–1996. The longest main span is 110 m, the breadth – 32 m. The carrying element of the bridge is a single arch in the span, which forks at the supports. The platform is attached to the arch by steel cables which are anchored at the ends of cross splint girders. At the same time, the platform is a tie which takes on a significant thrust value. As a result, the external supports carry primarily vertical loads.

The bridge is indisputably the dominant feature of the lowland landscape. Its dimensions, colour and shape also dominates when compared to small buildings of Ostrołęka. One could say that the domination is quite overwhelming and there is no consistency between the bridge and the landscape. That is true, but here this domination is very interesting exactly because of the contrast between this extraordinary bridge and a provincial and somewhat accidental architecture of the housing estates, Fig. 4.7.12.b.

Let us finish the overview of arch bridges with a bridge in Mérida, Spain. The last decade has seen the brilliant triumph of bridges designed by Santiago Calatrava. The reasons for his success are: his excellent sense of steel architectural structures, the use of the colours of Spain and an excellent application of the development tools of modern computational mechanics as well as a brilliant sense of design.

a) b)

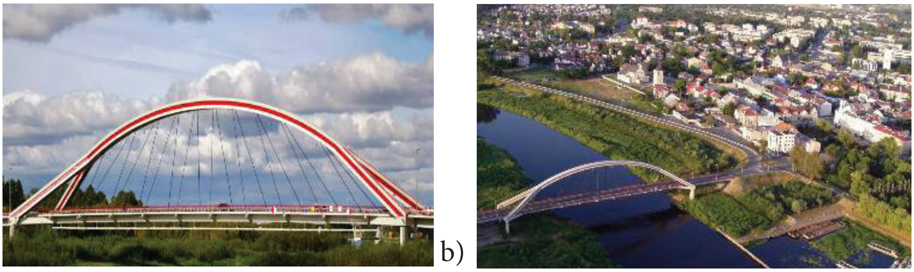


Figure 4.7.12. The steel arch bridge over Narew River in Ostrołęka, Poland; a) Side view b) Bird eye view[108]

The extending structure – traffic platform – is a continuous one. On the axis of the bridge there is a strong beam element which functions as a pedestrian-bicycle passage.

On the side surfaces of the beam, in its upper part, along the edge lines the rope hangs from the arch. At the bottom there are clamped cantilever plates for vehicle traffic, Fig. 4.7.12.b–c.

The arch is the main carrying element. The arch can be seen as a composite structure made of steel and concrete. In the span, the arc is formed as a steel lattice, whereas at the bedhead the arch elements are made of massive concrete. In addition to the aesthetic approach i.e. the contrast between parts of concrete and steel, they have also a mechanical interpretation. It is commonly known that in case of the dynamics of the most sensitive area of a simply supported bridge arch there are surrounding points at at a distance of $\frac{L}{4}$ from the supports, where L is an arch span. There the dynamic excitation is always first noticeable. The length of the concrete bedhead in the discussed case is ca. $\frac{L}{6} < \frac{L}{6}$. However, the carrying-deck is not a simple element but a continuous one. This means that due to stiff concrete at beds the support zone here has been shifted due to the continuous nature of the platform. The designer bypassed the dynamically weak spot. This is also the mechanical explanation of the final architectural view of the arch. Should there be any doubts, it is advisable to test it yourself by means of elementary MES modelling taking the dynamics into consideration.

A few more words about the delicate context of Robert Maillart's bridges. Fig. 81.d shows a view of the underside of the carrying-deck. There you can see the rib-plate of roadway zones with disc-shaped parabolic complements. The form was used in one of Maillart's bridges. It encourages the viewer to find suitable pictures in the *cloud*.

While the suspension presented in Fig. 4.7.12. runs down to the transverse splint beams, in the case under consideration the bridge designer applied the transverse prestressing. The prestressing cables are visible in Fig. 81.d.

[108] by the courtesy of Piotr Brichacek, Briho

Figure 4.7.13. The Lusitania Bridge in Mérida over the Guadiana River a) Side view b) View along the bridge c) Suspension d) Bottom view *(by SLK)*

The bridge technical data and a small gallery of awful photos can be here {[109]}. Let us only notice that the arch characteristic ratio is of $\frac{f}{L} = \frac{32m}{189m} \approx \frac{1}{6}$ . This means that the bridge could be classified as a shallow one, not high.

The residents simply call the bridge *Puente Blanco*. Arch bridges are an endless story. Here, several objects were chosen, in a very subjective way, to discuss their aesthetics in terms of architecture and construction using criteria which come directly from structural mechanics. Of course, a running narration can be guided quite differently. However, one way or the other, the beauty of arch bridges can be easily demonstrated.

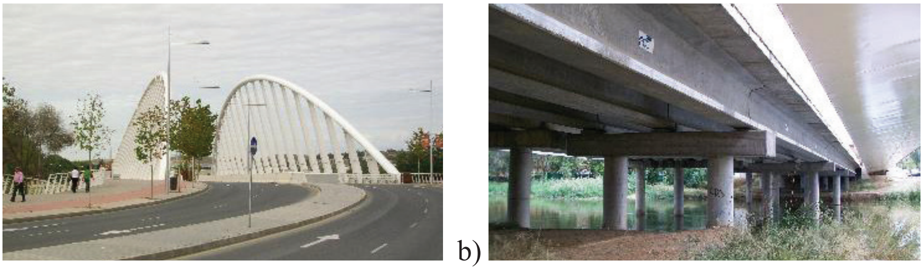
Instead of a chapter conclusion, we shall now prove the following theorem:

*The bridge arch shape is more attractive than you expected.*

Proof: see Fig. 4.7.14.a-b, by which quod erat demonstrandum.

There are many cities first criterion where in urban planning is attractiveness. In the Fig. 4.7.8. an average beam bridge made with prefabricated elements was bedecked with arches, which in essence are dummy arcs.

[109] http://structurae.net/structures/lusitania-bridge; [03.12.2015].



a) b)

Figure 4.7.14. The arch bridge over Tajo River in Toledo *(by SLK)*

## 4.8. Influence of construction materials development on a bridge image *(ALT)*

Various materials were used in construction of bridge structures: plants, wood, natural stone, glass, concrete, cast-iron, reinforced concrete, plastics. The materials used for bridge construction have changed with time and therefore the appearance of structures has changed as well.

The appearance of wooden bridges (Fig. 4.8.2.) or stone bridges (Fig. 4.8.1.) from ancient until modern times, based on natural stone forms (Fig. 4.8.3) and plants (Fig. 4.8.4.) observed by man in nature does not differ significantly. It was not until the introduction of new materials and technology in the 19th century, such as cast-iron, steel, concrete or reinforced concrete, when significant changes in the appearance of bridges were visible as new types of constructions appeared (Fig. 4.8.5, 4.8.6., 4.8.7.).

Figure 4.8.1. Bridge of stone, Basteibrücke – rock formation constitutes one of the major tourist attractions of the National Park Saxon Switzerland, the Elbe Sandstone Mountains in the eastern part of Germany; source: [110]

[110] https://pl.wikipedia.org/wiki/Bastei#/media/File:Basteibr%C3%BCcke_morgens_%28Zuschnitt%29.jpg

Fig. 4.8.2. Esing bridge (Essinger Brücke) – the longest wooden (GluLam) bridge (footbridge), stressed ribbon bridge in Germany *(by ALT)*

Figure 4.8.3. Rock formation imitating bridge; source: [106]

Figure 4.8.4. Root formation imitating bridge; source: [111]

[111] http://www.bbc.com/travel/story/20150218-indias-amazing-living-root-bridges

In recent years new construction materials appeared in bridge engineering: new generation concrete and concrete-like composites, plastics reinforced with various types of fibres (glass, carbon), new generation and selections of structural steel, modern repair, insulation and finishing materials, new types of rust proofing for steel and concrete structures (Fig. 4.8.5, 4.8.6., 4.8.7. Such materials give the possibility to meet the modern requirements more effectively and define new trends in the development of bridge engineering. New, competitive technologies and unseen types of structures occur. Apart from the benefits of using them, i.e. reduced overall cost, increased durability, improved technology, increased effectiveness etc., we get a new (more attractive) image of modernized or newly built structure (Fig. 4.8.5, 4.8.6., 4.8.7.).

Figure 4.8.5. Overpass Millau, is a cable-stayed bridge that spans the valley of the River Tarn near Millau in southern France *(by ALT)*.

Figure 4.8.6. Gateshead Millenium Bridge; source [112]

[112] "Gateshead millennium bridge open by Mike1024" – Photo taken by en:User:Mike1024. Licensed under Public Domain via Commons - https://commons.wikimedia.org/wiki/File:Gateshead_millennium_bridge_open.jpg#/media/File:Gateshead_millennium_bridge_open.jpg

Figure 4.8.7. Langkawi Sky Bridge, Malezja 700 a.s.l.; source: [113]

Introduction of new materials and technology, as well as production of faster and faster means of transportation have changed the way the engineer perceives the very obstacle.

Fig. 4.8.8. presents two coexisting bridge structures. One of them is from the beginning and the other from the end of the 20th century. The old, suspended bridge connects the banks of the river which is not perceived by the engineer of the modern structure. Today the obstacle is not the river but its valley. New times, new materials and new technologies have changed completely the attitude to road structures, which is clearly visible on Fig. 4.8.8.

Figure 4.8.8. Adjacent bridges from different eras around near the town of Silvan in southeastern Turkey *(by ALT)*

[113] "Langkawi sky bridge" by Flickr user "The Dilly Lama" – https://commons.wikimedia.org/wiki/File: Langkawi_sky_bridge.jpg#/media/File:Langkawi_sky_bridge.jpg

Time difference of elevations of shown bridge is 800 years. Until 1950 the historic stone bridge incessantly served its traffic functions. The white was the dominant color in background of agricultural plateau. Centuries duration of the bridge left their mark in consciousness of the people. A new RC bridge is a type of signum temporis. It constitutes an exceptionally aggressive and non-interesting accent in the original peace. The bridge does not complies with high requirements of the current traffic standards, additionally at the same time, simply disturbs the synergy of the surroundings. [Lagoda, Leniak-Tomczyk, 2007a].

Any technical progress and new materials provide new, amazing possibilities of shaping bridge structures. They require, however, deeper reflection and more careful approach because bridge construction is not only a technical but also a social activity. Apart from this, lately the act of building a new structure has been frequently connected with brutal interference with the environment. When the opportunities given by new materials and technologies are used in a rational way, the bridge structures can be functional, economical and beautiful but they should also comply with the principles of widely understood ecology. The reason why bridges in urban, mountainous and low-lying areas look different is not only the constructor's attempt to achieve harmony with the landscape but it is also attributable to various economic possibilities of the areas where new structures are created as well as to the financial resources of the investors. With today's rapid advancement of the material industry there are potential possibilities to build light, sleek, almost sophisticated bridge structures. Due to the development of modern technologies there are also chances of building highways and the entire infrastructure with much less effort than before while observing aesthetic requirements and the current ecological trends [Lagoda, Leniak-Tomczyk, 2007a].

The term "*sustainable*", started by the publication of the Brundtland Report in 1985 and its confirmation in 1992 with the declaration from Rio de Janeiro, has become a well-known, global, political paradigm. The term "*sustainable*", meaning acceptable and possible to maintain, comes from the Latin word "*sustinere*" which combines two terms: "*to be born*" and "*to survive*". Sustainability may therefore be translated simply as long-term compliance, balance [Lagoda, Leniak-Tomczyk, 2007a].

Responsible bridge creators in the design process should consider the entire life of the future structures, from material creation until the end of bridge existence, not only in terms of their weight bearing properties and their usage but also from the point of view of ecology, economy and taking into account the social and cultural aspect (LCA methods are discussed in the book entitled *Assessment of the impact of roads on the environment*). This makes us evaluate the impact of the structure on the environment by regional development, the use of materials, material and intellectual energy, as well as by inspiring impressions and aesthetic feelings. Currently, the investors are visibly more and more interested in setting increasingly higher requirements for bridge construction, which influences the design process. This leads to rapid development of new types of structures, materials and technologies, which in turn lead to new levels of global competition. This does not mean that we are not supposed to use traditional building materials such as stone, bricks or wood. Stone and bricks are ideal for making various internal lining. They enable creating appropriate climate in the environment and they perfectly harmonize with this environment [Leniak-Tomczyk, Lagoda, 2008].

The world more and more often notices positive aesthetic aspects of the technical activity caused by using wood as the construction material. A spectacular proof of this is the footpath through the Rhine–Main–Danube Canal in Essing (Fig. 4.8.2). The 192 metres long structure is situated in the beautiful scenery of the Altmühl river valley and runs through limestone hills overlooked by Randeck castle. The bridge is intended for pedestrians. It is the first wooden ribbon structure in which bridge span (73 metres long) carry vertical loan distributed in 90% to longitudinal forces and only 10% to bending moments.

Currently the manufacturers and the laboratories around the world work on new technologies which will maximally shorten the construction time, minimize the amount of equipment and materials used and will have the lowest possible negative impact on the environment (the shortest possible, the lowest possible noise level, the minimum emission of air pollutants and the lowest energy consumption). This way they will form part of the widely understood canons of aesthetics seen from the naturalistic perspective. The structures built in accordance with such principles have already been created, e.g.: the highest overpass in the world in Millau (Fig. 4.8.5) or the bridge in Hesse made using plastics. Road bridge made of plastics, the assembly of which lasted a day only, was built in Hesse near Friedberg in Germany. It was first prepared in the factory and then transported in whole to the building site. The road slabs of the bridge are made of polymer reinforced with glass fibre (FRP) and were stuck on two steel load bearing components. The structure was assembled without screws or nails. The bridge, which is 27 metres long, 5 metres wide and its weight is 80 tones, is suited for all types of modern vehicles. The structure complies with the standards of Eurocode 2010, which is the European building code, adopted by the European Commission for the construction in the public sector. It is expected that such a bridge will not require repairs even for 50 years since the composite material does not undergo corrosion. The construction of conventional structures, e.g. concrete, lasts quite long which leads to equally long traffic impediments and high energy consumption caused by such technology. In the case of traditional bridges often after 15-20 years it is necessary to carry out thorough maintenance works. Long-lasting construction process and frequent maintenance works have a major impact on the environment in the vicinity of the bridge and as a result on the bridge appearance. The bridge which remains in the same form and condition for a longer time has a definite aesthetic advantage over the one which undergoes destruction and deterioration after a shorter time.

The development of technology shows that the times are coming in which people in their striving for improvement will focus not only on precision but also on subtlety and beauty. We can venture a thesis that the world will achieve balance when the science and culture, the technological development and beauty of the forms around us will complement each other [Lagoda, Leniak-Tomczyk, 2007a].

## 4.9. Bridge facilities and environment in the bridge vicinity *(ALT)*

Environment in the bridge vicinity in the aspect of aesthetics requires an analysis of harmonious integration of bridge structure in its surroundings. Depending on the obstacle we neec to overcome using a bridge, the surroundings will differ and, what follows, the aesthetic principles of the bridge formation and composition will differ as well.

In the case of bridges located across river valleys, gorges, grassland or other natural formations, they should be integrated in such a way that they do not form the so-called ecological barrier. Such partitions may contribute to considerable fragmentation of the environment and to isolation of vegetation groups and animal populations, dividing the landscape into patches, limiting the possibilities of wandering, dispersion and feeding, destroying forest ecosystems, biotopes of river valleys and partitioning protected areas. The consequences of mistakes in design and construction of bridges, in particular in valleys of rivers, may be very serious: floods and significant reduction of biodiversity or even extinction of certain species.

Currently most large rivers in Western European countries show signs of significant natural degradation. The rivers in Holland, Denmark, Austria and France are deepened and regulated, with a number of dams in the form of e.g. bridges, and they resemble artificial, concrete channels. The valleys of Polish rivers (Fig. 4.9.1), which are only partly regulated and poorly utilized, are still environmentally unique in Europe.

a)  b) 

Figure. 4.9.1. a)-b) Bridge on the Krzna River within regional Road No. 698 – the area of Neple village in Poland *(by ALT)*

It is the river valleys which are the most valuable ecosystems in Europe due to the occurrence of unique habitats of high biodiversity which are conditioned by the existence of a watercourse. In natural river valleys or river valleys slightly modified by people a wide array of ecosystems occurs. Such ecosystems provide favourable conditions for the existence and development of numerous species of plants and animals:

- aquatic ecosystems: of rivers, ponds, oxbow lakes, other periodic and permanent watercourses and decorative ponds, peat bogs;
- forest ecosystems: marshy meadows, alder swamps, woods and transitional forms between them;
- ecosystems of forest covers and bush covers;
- meados ecosystems: alluvial meadows and pastureland, both damp and fresh.

Riverside riparian forests are one of the richest habitats of plants and animals in terms of species on our continent. Due to high diversity of ecosystems the valleys of rivers support the existence of numerous animal populations, in particular of birds in danger of extinction and many species of plants. If we interpret aesthetics adopting the approach of naturalists, such as for ex. Carlson [Carlson, 2008], aesthetic integration of a bridge in the environmental surroundings means integrating the structure in line with the principles of widely understood environment protection.

The impact of bridge as a barrier depends to a great extent on the location of the structure and on the structural and spatial solutions which were adopted. In river valleys treated as ecological corridors the most beneficial solution from the point of view of environmental protection would be to prohibit building any bridges. It is impossible to accomplish, though, therefore we should take action aimed at preventing isolation of local populations already at the stage of designing a structure. Bridges should be situated in such places where anthropogenic activity is already significant (in the vicinity of villages, towns) and far from natural ecosystems. In the case of bridges for animals, however, it should be the other way around: they should be placed as far as possible from residential areas. The best solution would be to consult the issue of bridges location with natural scientists and landscape ecologists who will define the least environmentally harmful location for the bridge. Before the construction starts we should also carry out an analysis and describe how a given area is used by the local fauna. This will enable optimization of bridge location and application of a number of protective measures (e.g. building additional animal passages).

As far as structural issues are concerned, in order to enable the largest possible number of species migrate under a bridge, bridgeheads should be located at the greatest possible distance from the river bed. Placing bridgeheads even a few metres away from the river gives (at least some) animals an opportunity for using the area underneath the bridges to travel. Rail and road bridges constitute quite a solid ecological barrier, especially if such bridges are placed too low over the valley. Higher foundation of bridge increases the chance that more animals will overcome such obstacles.

It is also necessary to repair as soon as possible the bridges which already exist on a given river and which are in a bad technical condition and adopt them to pro-ecological principles. If such bridges are over valleys which are already identified as ecological corridors, then the repair and modernisation should be carried out in line with all the principles and legal provisions related to the protection of environment and nature (energy saving, noise abatement recommendations, machines with low emission of pollutants to the atmosphere, high pace of works, environmentally friendly materials etc.). Leakages to natural waters, which occur during construction works, should also be prevented. Such leakages may have a negative impact on fish and aquatic invertebrates because they contain substances which block respiratory organs of animals living in water. Such substances may lead to disappearance of fry, if they are carried by the river current and deposited at the bottom. If in effect the watercourse gets purified, the entire river ecosystem becomes destroyed.

The volume of traffic on the road at the road operation phase is also an important problem. If a bridge is situated along a service, local road, where the traffic is low or the vehicles travelling on the road are mainly motorcycles, sporadically passenger cars, then the danger of water pollution caused by bridge runoffs entering the river is much lower than in the case of e.g. a highway or an expressway. Failures, accidents or extraordinary dangers to the environment may also occur; they pollute biotopes of river valleys for many years or even irreversibly. For this reason, the location of a given structure, the applied water and sewage management solutions and interdisciplinary cooperation related to these issues are so important.

The activities in the closest vicinity of bridges are also relevant. Removal of riverside trees and plants and artificial protection of river banks, used within bridges, decrease the amount of organic material which is the basis of food chain of all the aquatic life forms. Together with lack of shadow they lead to destruction of feeding ground and spawning areas of fish. Thus, we should avoid removing plants within bridges and instead strengthen the riverbed and slopes, also on bridgeheads, using natural and environmentally friendly materials (such as ground cover, perennials, hydro-seeding, biogeotextiles, natural stone, fascines). We should also take appropriate care of plants surrounding the structures, first at the stage of their planting and then their cultivation [Lagoda, Leniak-Tomczyk, 2007b].

Figure 4.9.2. The overpass is dominated by the embankment, highway No 4, Poland *(by ALT)*

When bridges pass over artificial obstacles, e.g. other roads, we talk about overpasses and underbridges. In two-level junctions the road is most frequently linked to the overpass using an embankment. In such situations it is important to design in detail the connection between the road and the overpass. Professional, aesthetic finishing of the embankment which the bridgehead is integrated with may be of crucial importance in the evaluation of the general appearance of the structure and of its surroundings. The embankment must be strengthened in order to look aesthetic and to perform its function well. This can be done in a number of ways. In older structures the easiest way was to sow grass which turned into turf or to grow other plants which perform similar functions. In most cases embankments reinforced in a natural, even way, covered with turf allows for exposing the structure and not the access to the structure. As clearly visible in Fig. 4.9.2, proper shaping, reinforcement and maintenance of embankment places the overpass in the foreground and this way the overpass is not dominated by the embankment.

Unfortunately, sometimes the situation is different, as in the case of structure Fig. 4.9.2. The dominant, which in this picture is the embankment expanded to gigantic size, attracts the attention of the observer and overshadows the main structure. Such an impression is intensified when the embankment and the bridgehead together with the superstructure are of a similar colour. It is then difficult to distinguish individual elements and failure to do so is contrary to the principle of entirety and clarity of form (the chapter "Static Scheme choice"). In the presented structure various elements are not divided, even in terms of colour, which would make it much easier to interpret their form and to divide functions. Bridgeheads, due to their function, are very often elements with large, empty areas. People avoid emptiness because they realise what is required to fulfull it. An evidence of this, not very desirable, is sometimes graffiti. Empty walls of beachheads are visible in Fig. 4.9.2; here the negative impression is intensified by concrete stabilisation of slopes. It is evident that the proportions between massive supports and very slender superstructure are not retained here. The sense of emptiness may be masked in various ways. One of them is to use colour. We can also fight with emptiness by breaking the planes, dividing simple elements into a few blocks with different lighting. Finally, decorative elements may also be used. In such cases it is recommended to apply local symbols or motives related to the region. It would be good for the decorative elements to be somehow related to the region which the road goes through. Typical structures which are built on a mass scale over highways or expressways do not have to be identical everywhere. Differences will help avoid monotony. The surface texture, decorative elements or supports may differ and this may be achieved by way of various textures used to finish the concrete surface. If natural stone occurs in the area and the structure has masonry elements, the natural stone should be used for building or lining because it is often visible in the local landscape as rock or an element of buildings, brick foundation, fence etc. Brick lining should be used in the areas where natural stone is not present. Smooth surfaces with rounded edges should be used whenever we need to demonstrate the lightness and slenderness of the structure. In the forest and rural environment it is good to preserve the natural traces of formwork showing the rings of different degree of roughness. In green and leisure areas it is recommended to accentuate the environmentally friendly colours of natural aggregates. In industrial and urban areas in turn it is better to use panel formwork (steel or plywood) which forms smooth, orthogonal pattern. For enclosures we can also use ready-made, industrially manufactured prefabricated materials. We should bear in mind that on bright surfaces the contract between light and shadows is more visible and the texture of such surfaces may be shallower than in the case of darker surfaces. Dark surfaces in turn, in order to be visible, require deeper shaping. The colours should be selected with great caution, though. What looks fine on paper does not necessarily work in reality. In order to use bold colours and large contrasts the designer must have knowledge and skill. However, if it is decided that the embankment will be stabilized using stone lining, concrete fittings or other artificial elements, it is better to limit the paved area to the necessary minimum in order not to allow domination of the embankment over the structure and not to create elements with large and empty areas. Limiting the paving to the area under the bridge is visually more beneficial to the structure and its surroundings. Paving underneath the structure may also be an element characteristic for the road, as seen on the example taken from a French motorway [Lagoda, Leniak-Tomczyk, 2007b].

Wherever possible, however, stabilisation of embankment slopes with greenery will always be better from the point of view of the aesthetics than paving or concreting, in particular in natural surroundings, where even if the greenery on a slope is poorly maintained it is more beautiful than the best paving on a slope. This thesis is additionally supported by the observation that greenery, as opposed to objects such as artificial parts of embankment enclosure, has one important advantage: even if it is not very carefully cultivated, it changes with time and becomes more and more beautiful.

One of the tasks of a 21st century engineer is to adopt such an approach to bridge structures formation which will ensure that construction of a new structure or modernization of an existing one are adjusted to and compliant with the principles of ecoengineering and widely understood aesthetics and ecology. The structure and its surroundings should be treated using an integrated approach, together with all the elements, with landscape and ecological relations, preserving harmony of the technology with nature and the cultural values of a town or region.

## 4.10. Availability and usability *(ALT)*

Over the centuries of their existence bridges, depending on the epoch, have performed various functions: starting from strategic (Hannibal's bridge in Martorell), through being the place of trade or even residence (Ponte Vecchio), up to becoming the place of meetings, friendly conversations, love confessions and heated discussions, as the bridge of the hippies in Amsterdam or the bridge over the Drina river in Visegrad described this way by Ivo Andric[114].

Bridges, which have become a permanent element of the natural and cultural landscape, have accompanied people for centuries not only as structures. They have been, and keep being, present also in the art, literature, poetry, even in everyday language ("burn your bridges", "it's all water under the bridge"). All this demonstrates how im-

[114] Andrič I., 1970 - Most na Drine a iné prózy. Slovenský spisovate, s: 3□14.

portant these structures are and what a significant and multifaceted role they play in our lives. For this reason, it is important from the human point of view that bridges respect two principles: availability and usability. Even Vitruvius in his *Ten Books on Architecture* [Vitruvius, 2014] stated that the public utility places, including road structures, should be constructed taking into account comfort and public benefit.

Bridge, overpass, footbridge: they can all comply with the principles of aesthetics discussed in previous chapters while being constructed properly and correctly and being harmoniously integrated with the surrounding landscape, stirring up at the same time positive aesthetic feelings in the recipient, but if they are not functional and easily accessible to the users, they will only be art for art's sake. The question then arises: does the existence of such structures make sense?

Figure 4.10.1. Footbridge is not usability[115]

A bridge is or may be a kind of a work of art. Nevertheless, as opposed to a sculpture, a painting or a piece of music, a bridge is used by people also for a clearly defined useful purpose, i.e. to pass through an obstacle over which it was placed. This is a matter of relations between the art and technology, the relation between these two and the question whether technology is, may be or should be beautiful, or maybe it should only have useful features, which the aesthetics have pondered over for thousands of years. For example, architecture, construction, sculpture and painting were perceived by ancient Greeks as being far from poetry, music and dancing. The former created objects to be watched and used, while the latter expressed feelings. Should a bridge be beautiful or rather useful, or maybe both?

[115] https://upload.wikimedia.org/wikipedia/commons/1/1b/SFTGMoonBridge.jpg

Currently the public infrastructure, including bridge structures and roads, should be easily available to everyone, also to the disabled, in accordance with the equality principles [116]. In the European Union the guidelines related to bridges, including their availability, differ slightly.

In general bridge structures, depending on their function, size, type of structure and the type of road within which is situated, may or should include the following elements, which facilitate availability and usability:

- sidewalks,
- cycle paths,
- slope steps,
- ramps.

Moreover, availability of bridges may be considered not only in relation to people but also to animals. The structures for animals (ecoducts, landscape bridges) should be located in such places where the human activity is close to none or non-existent, at least a few hundred metres from the boundaries of the places of human activity. It is good to locate bridges for animals in excavations, which makes it easier to fulfil the condition of acceptable surface inclination. Depending on the country the rules governing location, construction and structure of bridges for animals are slightly different. In many countries (e.g. Canada, USA, some European countries) the design, implementation and maintenance of bridge structures within road systems is connected with pre and post implementation monitoring of biotopes dynamics, which facilitates considerably preparation of guidelines. In Canada detailed, long term research programmes are carried out which focus on the migration of animals, in particular within protected areas (e.g. Banff National Park) [Clevenger and others, 2002]. The principles of building bridges for animals in various countries were discussed in detail in the book entitled Bridges and ecological transitions.

The parameters of elements used in bridge structures which facilitate availability and usability of such structures will be different depending on many factors, including the country in which a given structure is located, who is to be the user of such a structure, the category of road within which the structure is situated, the size of structure, over what obstacle it is placed etc. Therefore, we should always look for the principles of construction in relevant guidelines or legal provisions (a list of guidelines and legal provisions related to bridges in selected EU countries is presented in chapter 6.).

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[116] Standard Rules on the Equalization of Opportunities for Persons with Disabilities by UN, 20 December 1993; Convention on the Rights of Persons with Disabilities by UN, 13 December 2006; European Disability Strategy 2010-2020, 15 November 2010, COM (2010) 636;

# 5. Aspect of aesthetics of the design stage of roads and bridges *(MD)*

Usually, the design of roads and bridges is associated with tedious drawing and enumeration of geometry and necessary parameters. Designers often forget that they create a product that should not only be functional, but also visually attractive. Modern technology offers a broad spectrum of possibilities with regard to the design visualization. It enables an investor to see the outcome of their investment at the concept stage. It is truly beneficial, because at this stage we can assess the validity of our decisions and make changes. Visualization is an inseparable aspect of architects' work, who use it as a tool to sell projects. The importance of visualization in the infrastructure construction can be illustrated by an old Chinese proverb: "A picture is worth a thousand words".

## 5.1. Different kinds of visualisation

The main means of visualization are an image, a photo or a board. Presently, the range of possibilities in terms of imaging projects has greatly expanded. Nowadays, a simple 2D visualization is not enough to sell a project. Programs to create animations and videos allow us to illustrate a ride over the designed object. Presently, you can submit projects using:

- static 2D visualization (photos, paintings, posters), 2D animation,
- 3D animation and movies,
- simple 3D applications based on the engines used in the creation of games,
- virtual reality (VR).

Visualizations in the form of photographs and images that present designing solutions are essential tools used to illustrate a wider range of technical and aesthetic details. Very often this form is used in public consultations and the promotion of a project in the press. Contrary to appearances, public opinion is an important source of information for a designer. Simple images can be cropped using basic programs for the infrastructure design. Such a rendered image is processed in software used by graphic designers in order to obtain greater realism. The examples of software used for this purpose are applications such as:

- Adobe Photoshop,
- Gimp,
- Photoscape.

Another way of imaging design solutions are animations and videos created on the basis of projects. With a wide range of applications such as 3ds max or Blender you can create animations and videos mapping the designed property realistically. These types of visuals are used in presentations of projects also outside the industry.

## 5.2. Visualisation: What it is and why it is important

The Polish Language Dictionary defines visualization as a *representation of something used as an image*[117]. In contrast, Wikipedia portal provides a more complicated explanation of the term, namely a *generic name of graphical methods for creating, analysing and communicating information. With the use of visualizations people exchange both abstract ideas and messages with a direct basis in reality. Nowadays, visualization affects scientific research. Also, it is routinely used in technical disciplines and medicine, for teaching purposes, and is sometimes conceived as a means of artistic expression*[118]. A definition of the concept of visualization in terms of infrastructure can be defined as a visualization of the project in a more readable, accurate and realistic way, with the use of available technologies and also by taking into account the characteristics of a target group. The way engineers prepare visualizations depends on the client. For a person who lacks technical knowledge simple forms of projects and drawings are not enough, so it is necessary to provide him with visualizations in the form of images, videos and animations.

Procedures as well as the necessity for continuous consultation of projects require an appropriate presentation of working results. The varying level of technical knowledge of recipients determines the way of presentation. There appears the necessity to make such presentations realistic and accurate. People who cannot read technical drawings must be able to understand the idea of the project. The role of visualization in the investment process is very important because it is a specific way of communication. The basic tasks of visualization are:

- communication function,
- technical function,
- marketing function.

Communication function is based on the transfer of technical information through pictures. It truly simplifies contacts with people who lack technical knowledge and therefore cannot imagine some solutions. The role of this function is greatly enhanced due to the need for public consultation and presentation of their work in a way which is accessible to the public. Technical function is based on the usage of visualizations to scan technical to check the correctness of localization and also to find potential collisions. Modern technology allows us to visualize the effects of designer's work. This gives the possibility of the continuous control of the project. In combination with BIM technology and software controlling collisions, it prevents from undesirable situations. For designers it is a very important function, because it helps to save money and time. The marketing function as communication is used to convey information. A free market requires each product to be advertised. Nowadays, both the designer and the design office must have a portfolio containing their past achievements. Visualizations are very helpful in this matter, the more realistic visualization the greater the likelihood that our offer will be accepted by wider audience.

[117] See Polish Language Dictionary (http://sjp.pl/wizualizacja) (27.10.2015)

[118] See https://pl.wikipedia.org/wiki/Wizualizacja (27.10.2015)

## 5.3. 2D Visualization

The first way of imaging was 2D visualizations made as simple sketches. Today, thanks to modern technology we can easily find an image showing the project from any perspective and with any lighting at any time of the day. With a simple example of an intersection, we can create a very realistic visualization. Using the documentation of a bridge, we can easily present it in a clearer way. Such visualization can be used as a starting material concerning the inventory building. The following is a sample project of junctions and six CABG bridge of composite structures with visualizations.

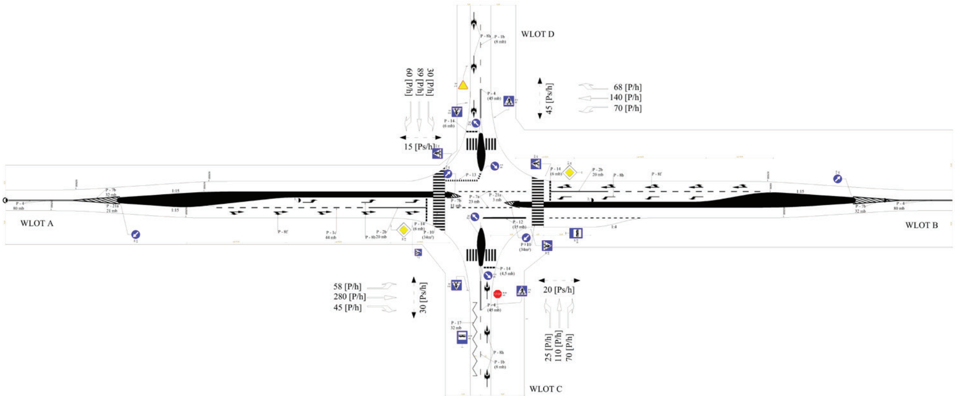



Figure 5.3.1. Output to achieve a 2D visualization. Plan of a simple 4-intake junction *(MD)*

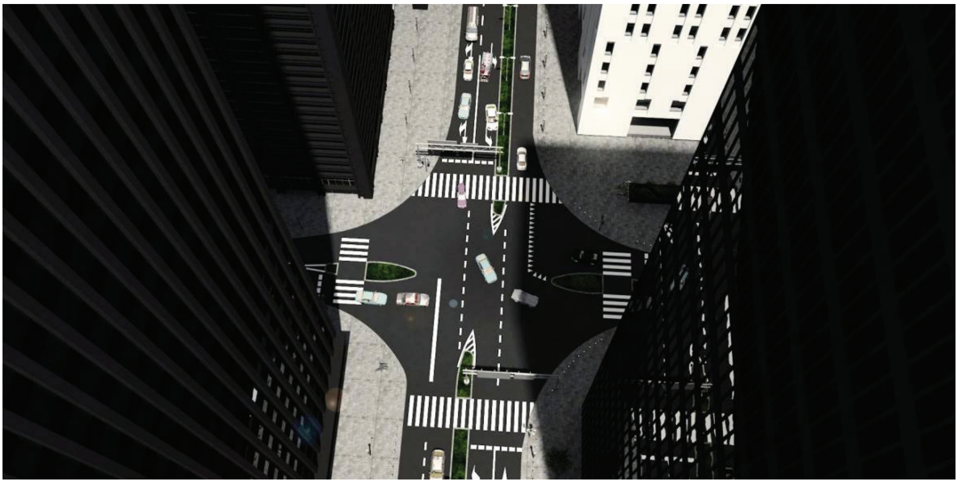


Figure 5.3.2. Once correctly positioned observer, can crop, render, and comlletethe visualization *(MD)*

Apart from the way of presentation shown above, there may be a number of other solutions in the form of a film or an animation of a flight over the designed facility. With modern technologies the only thing that can potentially limit the designer is their imagination.

Figure 5.3.3 Thanks to the 3D model you can change the perspective of the observer and visualize another part of the investment at any time *(MD)*

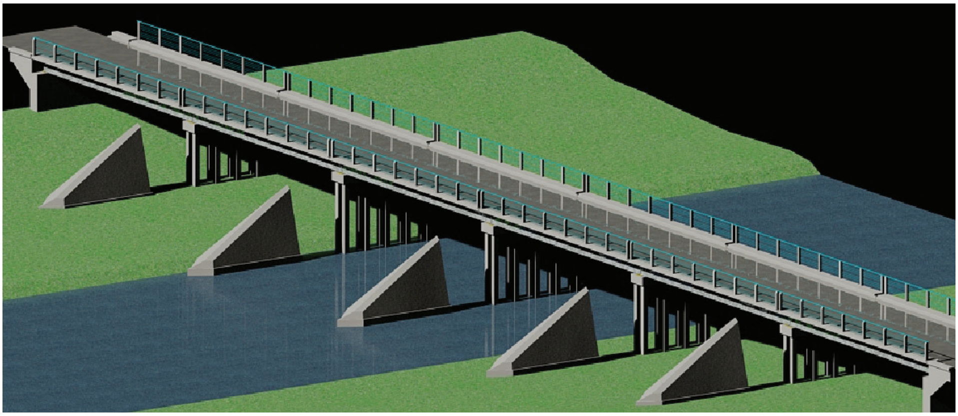


Figure 5.3.4. Visualization of the bridge in Chlewiska, Poland *(MJ)*

## 5.4. 3D Visualization

The basic solution to visualize 3D is animation and video. Once the project of a road is designed, thanks to modern programs you can pass on the 3D visualization in the form of an animation. With the ability to export the projects to the formats supported by the programs designed for creating and processing movies, you can create a very realistic presentation of the project.

With the development of information technology, also the technique of visualization develops. The next step to visualize is to create an application. With a simple program you can create applications that resemble computer games. The resemblance is not accidental, since they are based on graphic engines used in computer games. The application gives you the chance to explore the project in a way that simulates normal use, giving some freedom to move around the project.

Technology developers aim at presenting the project in the most realistic way. By combining electronic and audio-visual information technology the concept of virtual reality (VR) was created. VR is a set of hardware with software that creates a sense of immediate presence in the project. The world that is visualized is seen by an observer with the so-called the first person's view. By using the right accessories, you can get the effect of normal exercise every day, like opening a door. Such accessories are devices used in the game console, e.g. a camera that recognizes traffic and pads. Virtual reality is the most advanced tool for design visualization.


Figure 5.4.1. The basic set of company Oculus VR *(MD)*

The historical way of 3D visualization used even today is creating mock-ups. However, the development of technology has changed the approach to this question. In the past, the production of a mock-up lasted long and took a lot of energy. Nowadays, in order to create a model, you no longer need to have special artistic skills. You just have to use the technique of spatial printing. 3D printers have already been known for a long time but in the beginning, due to the high cost of these devices, they were rarely used. At the moment, the cost of a basic spatial printer oscillates around the price of a basic computer workstation. This technique allows you to easily create a basic mock-up of the proposed facility.

## 5.5. Software for visualizing infrastructure projects

Software companies know the market needs and therefore they constantly create and refine the software for visualization projects. Depending on the manufacturer and software version, you can create more or less complex visualizations in the form of photos, posters, movie clips or other. Today, it is no problem to illustrate a project, the only knowledge that is needed is how to use software. Most manufacturers of software offer very detailed tutorials that you can take advantage of.

#### *5.5.1. Autodesk*

Autodesk is one of the pioneer software supporting the infrastructure design. 2D Design passed into oblivion and was replaced by software that enables an instant preview of a work in three dimensions. The most famous program for designing roads, railways etc. – AutoCAD Civil 3D – meets all the requirements. At each stage, we can see a 3D model by two mouse clicks. AutoCAD Civil 3D has its own rendering engine, thanks to which we can make an initial version of the project. Autodesk offers a program for visualization. 3D Max Studio is one of the best and most widespread programs used to render, animate, model in 3D and create three-dimensional graphics. 3D Max has a very friendly and clear interface. The program is mostly used by professionals to create animated characters in computer games and movies.

#### *5.5.2. Bentley*

Developers of software for designers have created additional tools to visualize projects. Bentley also took into account the need for imaging projects. By using these tools the designer receives many benefits. The main advantage of built-in applications for rendering engines are reduced costs associated with the purchase of additional software. Another benefit is the ability to prepare a visualization in a very short time. Bentley Software uses an embedded engine to render. It is responsible for a realistic reproduction of designed elements. The process of visualization is completely automated. After a couple of steps, you can create a simple visualization for public consultation or for an investor. In case you need a better version of the program, you can export a project to multiple output formats. Embedded Solutions Bentley is very helpful and useful in the design and real-time visualization of a project.[119]

#### *5.5.3. Gimp*

GIMP (GNU Image Manipulation Program) is one of the most popular free programs used to process digital graphics. It is an equivalent of the famous (and not for free) Adobe Photoshop. Gimp's advantage is that is compatible with Windows, Linux, Mac OS and AmigaOS4.x. This program with its functionality is useful for creating graphics as well as retouching photographs. The major functions of the program are[120]:

- interaction with touch devices, such as tablet,
- work on layers,
- the ability to change the blend mode of colour layers,
- tools to edit colours,
- the ability to be expanded by using plugins (to support RAW image formats),
- the ability to filter and modify images (blur, sharpen),
- the ability to create custom brushes, gradients, patterns,
- the ability to work in RGB mode.

[119] Advertising materials Bentley

[120] https://www.gimp.org/ (27.10.2015)

The basic format of saving image files into GIMP is called XCF. The program gives you the ability to save and work files in JPG, PSD, GIF, TIFF, PNG formats. Also, you can read files such as PS, EPS, PDF.

### *5.5.4. Unreal Engine*

It is one of the great engines developed for the production of games, which was produced by Epic Games. In the early years it was used in creating the so-called first person shooter's games (first-person perspective) whose aim was to introduce the player into a game so that he/she could see the game reality through the eyes of its hero. At a later stage, the Unreal engine was also used in RPG computer games (computer Role Playing Game) or MMORPGs (massively multiplayer online role-playing game). Heart Unreal is written in C++, which is widely used by specialists to create different kinds of programs and applications. One of the greatest advantages of this program is the fact that it cooperates with different platforms: Windows, Linux, Mac, PlayStation 3, PlayStation 4, Xbox 360, Xbox One and iOS. Currently, there are four generations of Unreal Engine[121]:

- Unreal Engine 1,
- Unreal Engine 2,
- Unreal Engine 3,
- Unreal Engine 4.

5.5.5. Unity

Unity 3D is a graphics engine to create games and animation. With an easy, free access to this software, it has gained popularity among architects. This tool is also used in the infrastructure construction. Market needs and technology development generates new needs. By using Unity, one can create a number of interesting applications presenting ready projects. This software has powerful tools for texturing, creating light, generating an animation and defining the actions that can be performed by its user. Unity generates not only the picture but also the sound. A combination of visual animations and sound effects creates unique realism. A broad range of applications makes it possible to adapt the product to the customer. A completed animation can be saved as an application for playback on a computer with any operating system, a program compatible with the standard operating systems of mobile phones, an application for web browsers or as a VR software appliancation. A wide range of possibilities is a proof of the usefulness of unity in the design process.[122]

[121] See https://www.unrealengine.com/ (27.10.2015)

[122] See https://unity3d.com/ (27.10.2015)

## 6. Instead of a summary *(SLK)*

A mathematical aesthetic approach may lead to the need for final grades. However, aesthetics is not an area of closed solutions. They are helpful but artificial. Aesthetics is strongly humanistic by nature and still open to new challenges which arise with new objects, in this case bridges. Here are three examples of modern footbridges that cannot be qualified with absolute certainty.

The Gustav-Heinemann-Brücke located in the centre of Berlin, commissioned in 2005[123]. It is an object perfectly harmonized with the modern, spacious city environment. It does not constitute a prominent feature of this environment, although it is its distinct element. Technically, it is an interesting application of Vierendeel's[124] truss that combines the simplicity and uniformity of the stress of the structure. The structure is perfectly executed. Nowadays, the wooden path platform is widely recognized as a user-friendly solution. The green paint blends with the colour of the Spree River.

About this bridge you cannot say anything unfavourable. On the other hand, it is not a structure that evokes a strong aesthetic impression. Briefly, it's just there.

Ponte Della Costituzione (*Ponte di Calatrava*)[125], 2008, in Venice. Designing a new bridge in Venice is always a great challenge. The introduction of a new building into the characteristic tissue of the city is associated with an interference of new with the old. Venice, through its historical content, is a city for all who were there and those who will go there in the future. It is a part of the general consciousness. This is the fourth bridge over the Grand Canal. Already there exist three bridges created in the Venetian style. Calatrava's bridge contains basic architectural features of these bridges. It is of course different. Delicate arch is emphasized by the openwork steel carrying-deck and the use of tempered glass as pavement. Attention to architectural details, colours, transparency and the harmonious fusion of new technology with the historical environment is indisputable. The bridge is both pleasant to the eye and interesting.

However, as it turned out, the bridge has a drawback as far as its use is concerned. The construction transparency results from the glass elements of the deck. Unfortunately, the glass is rather slippery. For this reason, numerous pedestrian accidents have occurred. The bridge was closed for people with limited mobility. Thus, all the advantages of design and aesthetics have become a secondary matter due to the limited serviceability of the bridge.

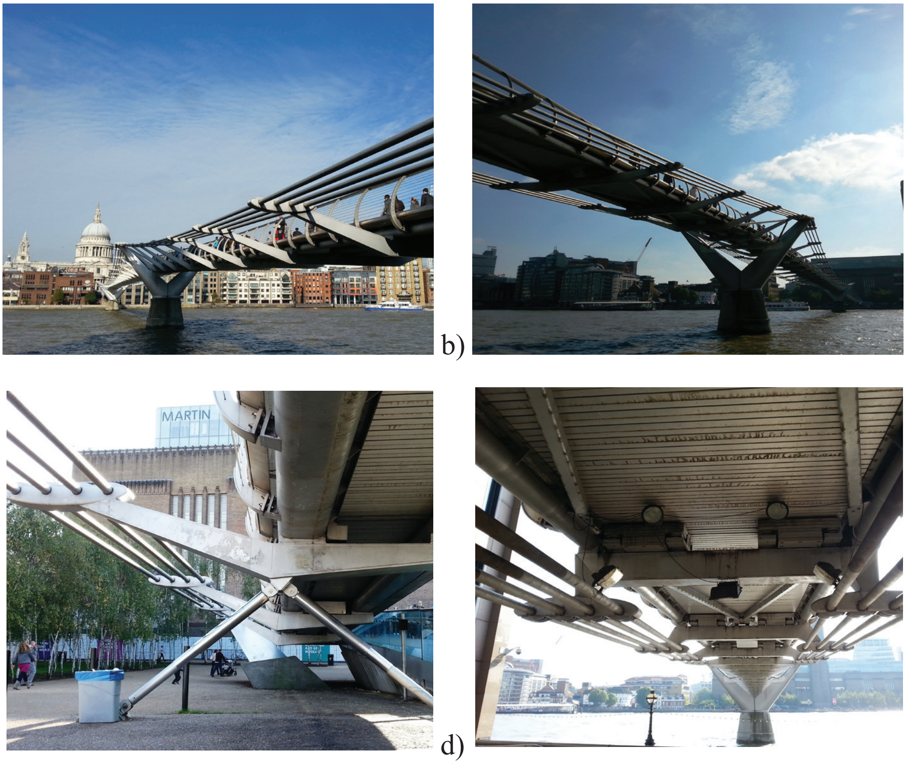
The Millennium Bridge over the Thames River in London, 2000/2002[126]. Millennium footbridge may be classified as a shallow suspension bridge scheme, Fig. 6.1.

[123] See https://de.wikipedia.org/wiki/Gustav-Heinemann-Br%C3%BCcke_%28Berlin%29, for example; [25.10.2015].

[124] Arthur Vierendeel (1852– 1940), civil engineering professor at the Catholic University of Leuven,.

[125] https://en.wikipedia.org/wiki/Ponte_della_Costituzione, [25.10.2015]

[126] https://de.wikipedia.org/wiki/Millennium_Bridge_%28London%29, [25.10.2015].




a) b) c) d)

Figure 6.1. Millennium Bridge a) Suspension cables b) Deck slings to the carrying cables c) Abutment d) Mass dampers

Buildings along the Thames in London represent typical Victorian architecture. Bridges from this period fit perfectly into this conservative image. Being modest, they do not dominate the city views. There is no revolution going on here. In the centre, along the river, walking from the Westminster Bridge, we arrive at the Hunger Bridge with suspended footbridges attached on the sides to pylons resembling port cranes, then the quite ordinary Waterloo Bridge and, further, the Blackfriars Bridge. The next bridge on our route is the modern and at the same time rather modest Millennium Footbridge followed by the Southwark Bridge, the London Bridge and, finally, the monumental – in terms of central London –Tower Bridge with stone façade pylons.

The most modern structure is the Millennium Bridge, on the extended axis of which one finds St. Paul's Cathedral. It is a small bridge, whatever it could mean. Simultaneously, it's a modern structure in every possible contemporary meaning of this word. Apart from pylons, the superstructure comprises ropes, which qualifies the bridge as a suspension one. At the same time, the cable layout resembles another bridge type, i.e. the ribbon bridge. The platform is suspended on, or, if you prefer, supported by Y-bar supports. Therefore, it can be described as a hybrid structure.

One of the small abutments is covered up. The pillars are massive but in the upper fork forming a Y shape. On the upper surfaces of the Y pillars the suspension cables were laid, 4 on each side, Fig. 6.1 b. By transverse ribs, which were mounted to cables, a bridge deck was suspended/supported, Fig. 6.1 c-d. Except for the massive pillars, the structure of the carrying-deck is delicate and transparent. Aesthetically, we have a juxtaposition of traditional Victorian buildings dominated by St. Paul's Cathedral in the background and a modern avant-garde metal structure. However, the dimensions of the footbridge are small in relation to the environment. Its strength lies in its visual difference and at the same time gentleness caused by the shallow system of suspension cables.

The story of the opening of the bridge is an example of the English sense of humour. The opening day had been expected for a long time. On 10 June 2000, ca. 5 thousand people were waiting to enter the bridge and walk to other side.

Due to such huge numbers of users the bridge became unstable and the usability limits were exceeded. It was not a breakdown emergency, but, nevertheless, the decision was made to close the bridge. One could conclude that during the opening of the bridge a certain load test was performed that indicated some design errors.

This case shows that professional modesty and humility are necessary characteristics of a designer proposing new technical solutions. Additional analyses and research were conducted as a result of which additional vibration attenuators were fitted. The bridge was reopened in 2002. It is one of London's highlights.

The depicted accident caused further increase of the bridge popularity. Currently, virtually every tourist wants to take a picture at the bridge.

The above overview of the three interesting bridges shows the subjectivity of aesthetic evaluations. As illustrated, a certain situational extravagance is important. Of these three bridges, despite initial predicaments, the first position is taken by the Millennium Bridge. Its indisputable aesthetic appeal and very turbulent history makes it a winner. Nevertheless, bearing in mind the subjectivity of that aesthetic evaluation, let us recall here an indisputably true Latin maxim: *de gustibus non est disputandum*.

# 7. Bridge glossary – basic terms and elements *(SLK)*

1

**Bridge.** Has a broad meaning, including various bridge structures. Here, however, it strictly denotes the bridge type that is spanned over water, be it a small watercourse, river, lake or sea bay.

2

**Viaduct, overpass.** An overpass is generally located above a stretch of land.

3

**Overpass.** The approach to the main span of Vasco da Gama Bridge (1998) in Lisbon by the multispan overpass / wharf of the length of ca. 17 km.

4

**Footbridge**. Footbridge – a bridge for pedestrians and emergency road traffic.

5

**Culvert.** Culvert – a short tunnel carrying a stream or open drain under a road or railway

6

**Temporary bridge.** A temporary detour bridge, e.g. for the reconstruction period of a permanent bridge. This system was designed by Donald Bailey. It consists of prefabricated steel trusses.

7 


**Multi span bridge.** A bridge of the number of spans greater than 1. On the photo the outer girders have the form of arched frames..

8 

**Aqueduct.** Aqueducts are rightly associated with Antiquity. They are bridge structures which provided water to cities in the days of the Western and Eastern Roman Empire and later, too. Currently, water supply pipes are suspended to ordinary bridges.

9 

**Mycenaean bridges**. Bridges built in the Early Bronze Age in the vicinity of Mycenae, Peloponnese. They were built with natural, so called Cyclopean boulders, without any mortar. Now, only two structures still serve as footbridges for tourists.

10 

**Clapper bridge.** A clapper bridge is also an ancient form of bridge, rather primitive. However, the carrying deck of the stone short plate is mechanically interesting; *Via de La Plata*, Spain.

11 

**Wooden bridge.** Wood/timber as a material for bridges has a long history which has not ended until now. Nowadays, mostly rural bridges are made of this material.

12 

**Vermicular bridge.** A vernacular bridge is a structure made by a non-professional, sometimes inexpertly, but effectively.

## *Truss bridge*

The truss is a very popular bridge scheme, especially if the bridge is long and heavy loaded. This is a very effective and, occasionally, aesthetically interesting solution.

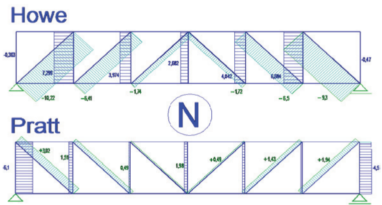
*13*

**Warren truss bridge.** The diagonal truss system (cross braces) resembles the letter W, often supplemented with hangers and posts.

*14*

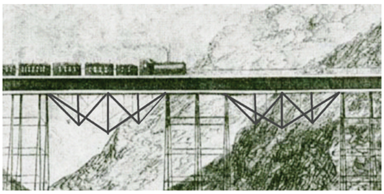
**Pratt truss bridge**
Cross braces have a form similar to the letter N, stretched when static.

*15*




**Howe truss bridge**
Also in this type of bridges the cross braces have a shape similar to the letter N. However, in this case they are compressed.

*16*



**Fink truss bridge**
The truss has the shape of an inverted triangle or a triangle system.

### *Design*

Designing is a process the final result of which is contained in technical drawings. The geometry of the bridge, its static scheme, materials used, elements of a road/railway, the design basis, technical standards and numerous other details are shown in the *Main Drawing*. It consists of 4 quarters which are depicted schematically below. The elements of the Main Drawing will be discussed further, too.

| Main Drawing | |
|---|---|
| **1. quarter**<br>Side view and longitudinal cross-section<br>Superstructure<br>Bearings<br>Under the bridge clearance gauge<br>Basic dimensioning along the bridge and ordinates<br>Abutments and pillars<br>Foundation<br>Riverbed, clearance gauge of traffic<br>Geotechnics | **2. quarter**<br>Cross-sections in the middle of the span and in the line of supports<br>Dimensioning and ordinates<br>Arrangement of traffic on the bridge<br>Cones of embankments<br>Safety facilities - balustrades, barriers, curbs etc.<br>Declines of pavement, elements of drainage<br>Bearings<br>Foundation<br>Expansion joints |
| **3. quarter**<br>Plan view of<br>- road pavements<br>- sidewalks<br>- arrangement of carrying elements girders/plate<br>Dimensioning and ordinates<br>Bearings<br>Abutment and pillars<br>Scarps, cones and embankment<br>Drainage | **4. quarter**<br>Bridge technical standards<br>Summary table of materials<br>The table with the name of the investment, theme and signatures of designers |

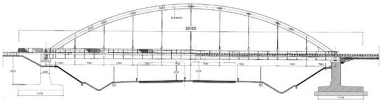
## *Arch bridges*

Aesthetically, the arc is almost always an interesting part of the environment. Hence, the frequent use of arches instead of competing truss schemes. There is a considerable variety of arch bridges as shown in the following examples.

Arches have been built since the days of Antiquity. The common materials then were natural stone, hewn stone and brick. Also wood was in use. From the modern point of view wood draws the arch bridge structure closer to the truss.

The introduction of forged steel and steel was revolutionary. As anywhere else, a new impulse to develop arches came with the use of concrete.

*17*



**Arch bride - side view.** A steel tied-arch bride with Langer (vertical) hangers. A side view.

*18*

**Arch bridge.** A steel arch bridge with Nielsen (inclined) hangers. The footbridge in Szczebrzeszyn.

*19*

**Arch bridge.** A tied-arch bridge with radial hangers (also inclined), the Apollo bridge in Bratislava over the Danube River.

*20*

**Timber arch bridge.** A two-hinged arch bridge made of GluLam, glued and laminated timber.

*21*

**Arch bridge.** A steel tied-arch bridge, Nielsen hangers. The bridge is of the *Barqueta* type. The bridge in Ostrołęka over the Narew River.

*22*

**Historic arch bridge.** Double deck, wrought iron, tied-arch. The Dom Luis I Bridge in Porto over the Douro River, (1886).

*23*

**Rome – city of arch bridges**. *Ponte Flaminio*, Rome. In the case of arch bridges one can spot a certain *eye* which consists of the arc and its mirror reflection. This effect is always amazing. Aesthetically, the viewer obtains more than just a bridge.

24

**Byzantine arch bridge.** An ancient stone bridge over the Euphrates River. A double parabolic arc is the carrying element.

25

**Multi span arch bridge.** A reinforced concrete (RC) multi-span arch bridge over the Tiger River in Hasankeyf. The deck is located on arches and traffic flows on the top.

26

**Ecological arch bridge.** An animal upper transition on a concrete-soil arch structure, Czechia.

27

**Arch culvert.** A steel-soil multi-plate bridge/culvert on the Czarny Potok near Zamość.

## *Suspension bridges*

The carrying elements here are a pylon/tower and a rope in a natural overhang. The bridge deck is suspended by hangers to the ropes. This type of bridges has a long history. Their origins can be tracked back to the footbridges made with natural lianas occurring in Asia.

Modern suspension bridges appeared with the advent of steel wire ropes manufactured by A. Roebling in the USA.

*28*

**Chain suspension bridge.** The Clifton Suspension Bridge (1864). Initially, instead of ropes, chain links with sheets of wrought iron were used. The massive pylons are made of bricks.

*29*

**Kiev suspension bridge**. The suspension chain bridge in Kiev over the Dnepr River (1853-120) was designed by Charles Blacker Vignoles. The bridge was blown up during the Polish-Bolshevik war by the Polish troops.

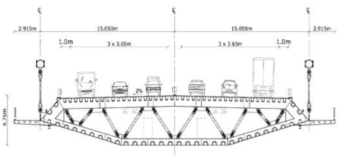
*30*

**Tacoma bridge.** Tacoma Narrows Bridge (*Galloping Gertie*) collapse in 1940. The cause of the crash was the use of signifcantly high plate girders of the bridge deck.

*31*

**1st Bosporus Bridge.** Bosporus bridge has the central span of the length at 1,074 m. The so-called low profile deck implies aerodynamic properties. Hanging cables are not vertical but stiffer zigzag ones.

*32*



**Izmit Suspension bridge.** Izmit Bay Suspension Bridge – the cross-section of low profile orthotropic bridge deck.

## *Cable-stayed bridge*

The main elements of a cable-stayed bridge are a pylon/s and straight cables. Their behaviour can be compared to the functioning of shrouds. Diagonal rods in the Bollman trusses also bring to one's mind cable-stayed bridges. The first bridge of this kind was built in 1873 in London, i.e. the Albert Bridge designed by Ordish and Bazalgette.

33 

**1st cable-stayed bridge**. The Strömsund Bridge (1956) over Ströms Vattudal, constructed by Franz Dischinger. It is assumed that this is the first contemporary cable-stayed bridge.

34 

**Central cables**. The Bridge of the Slovak National Uprising (1972) over the Danube – a steel pylon and a deck where cables are fixed in the middle of the deck. A cross-section reveals a two-compartment box. Outer sidewalks on the bottom cantilevers.

35 

**...under construction.** The Nissibi Euphrates Bridge under construction. The side cables are fixed to the ground through the concrete deck. The main span is made of steel segments mounted sequentially as short cantilevers. Both pylons are made of concrete.

36 

**Cable-stayed footbridge**
The old rail frame structure of the Hungerford Bridge (1864) is supplemented with footbridges on both sides. They are suspended by cables to the ‚port cranes'.

37 

**Rail cable-stayed bridge**
The Istanbul Metro Bridge over the Golden Horn (tr: Haliç), opened in 2014. A steel structure. The metro stops on the bridge.

38 

**Multi cable system**
The "deltoid" shape of pylons.
Norway, Trondheim region.

## Movable bridges

Movable bridges play an important role in the cities with extended systems of water channels and rivers, e.g. Chicago, Amsterdam and others.

39

**Cable-stayed bridge.** The "deltoid" shape of pylons. Erasmusbrug (the Erasmus Bridge) over de Nieuwe Maas (1996). The west short part of the bridge works as a bascule bridge allowing the ship traffic.

40

**Drawbridges** A double leaf bascule in the mouth of the Nieuwe Herengracht channel, Amsterdam.

41

**One leaf bascule bridge.** The Staalstraat Bridge in Amsterdam, completed in 1896. A one leaf bascule bridge.

42

A swing bridge of the double cantilever static scheme, Den Haag.

43

**Movable central span**
The Tower Bridge in London (1894) has a movable central span to allow the passage of ships or barges.

## Gerber beam scheme

The idea is illustrated in the graphs of bending moments engendered by the uniform load distribution. The hinges are placed in the beam points where the moment values are equal to zero. We can talk about the base/primary beam part and the upper/secondary one. It is analogous to the game of pick up sticks. Currently, the Gerber beam concept appears to be outdated, but, on the other hand, we cannot say what the future holds.

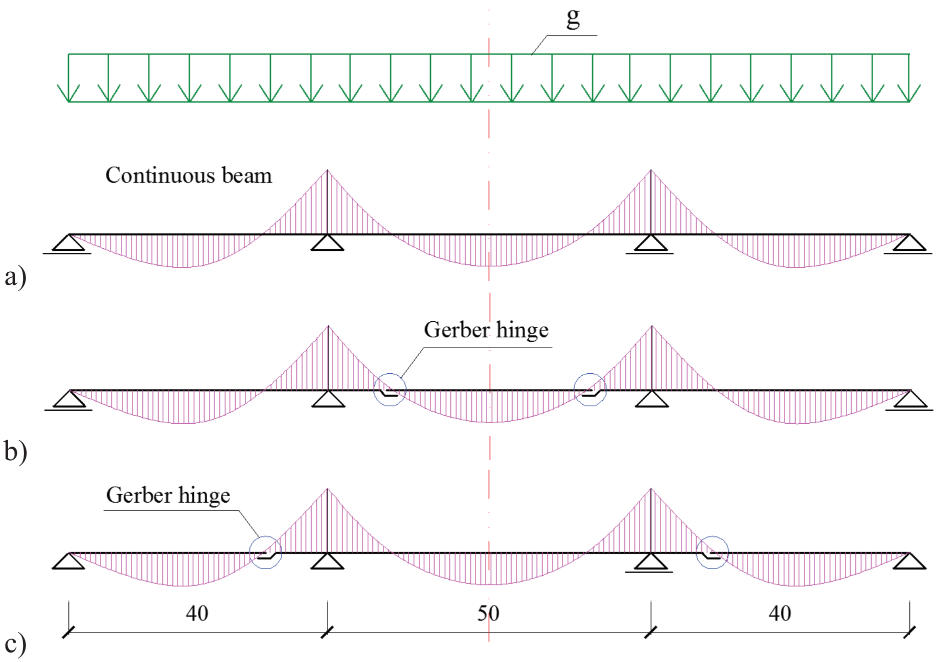



Figure 7.1. The Gerber concept of a hinge system a) the graph of bending moments in the case of a uniformly loaded continuous beam b) 1st option of hinge distribution c) 2nd option *(by SLK)*

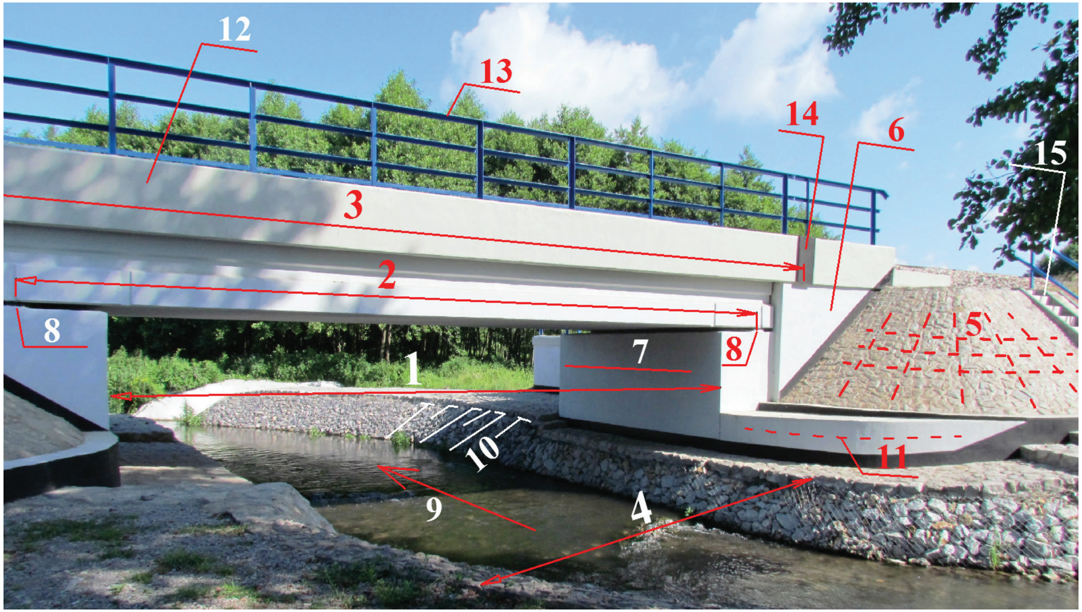
*44*


**Gerber scheme**. In the city of Puławy the old steel road bridge was built according to Gerber scheme in 1934. The shape of the upper truss belt corresponds to the graph of bending moments caused by permanent loads. The truss is not a continuous one. This is the so-called Gerber scheme. The Gerber hinge is circled in the illustration.
The bottom close-up shows the articulation in detail.

## Simple bridge

A simple or a one span bridge is the most important static scheme of all. A simple bridge is a one span plate or beam bridge structure supported at its ends on articulated bearings. Bearings can be movable or fixed in assumed directions and can be used in the cases of both road or rail bridge.

<u>The fixed bearing is located on the lower of the abutments.</u>




1) The distance between the abutment walls is called the horizontal clearance width as well as the horizontal light, and is denoted as $L_0$.

2) The distance between the supports $L_t$ is the theoretical length of a bridge.

3) This distance covers the length of a carrying deck (superstructure), denoted as L.

4) The distance measured on the level of the river bed *crown*, simply the width of the river.

5) Where a road embankment meets a bridge, it takes the form of a quarter of a cone – commonly called *a cone*; in the illustration, the cone surface is protected by a layer of natural stone. The cone slope is 1:1 or smaller.

6) A bridge connects with a road by wings which are immersed in the embankment. Here, the wing is called a hanging wing.

7) This is the breadth of an abutment, called a corps/wall of an abutment.

8) The line in the illustration indicates the position of a bearing – it actually indicates the line on which bearings are placed. This line can be a straight or a curved one.

6), 7), 8) and 11) form an abutment.

9) The arrow reminds that in the *Main Drawing* of a bridge the river always flows up.

10) The slope of the river embankment is 1:2 or smaller.

11) It indicates a retaining wall which supports the cone against sliding.

12) Cornice / drip. A cornice forms a visually important line in the image of a bridge.

13) Pedestrian balustrade.

14) The place where the carrying deck ends. Here, a dilatation occurs which is covered by an expansive joint.

15) Bridge operator's stairs.

Figure 7.2. Simple bridge - side view *(photo by Zygmunt Grzechulski)*

## Bridge cross-section

A cross-section, or section in short, is a component of the bridge *Main Drawing*. It is a result of the perpendicular cut of the bridge carrying-deck or superstructure. It shows structural and road/rail elements as well as other facilities. A cross-section is usually made in the middle of the bridge span or along the supports.

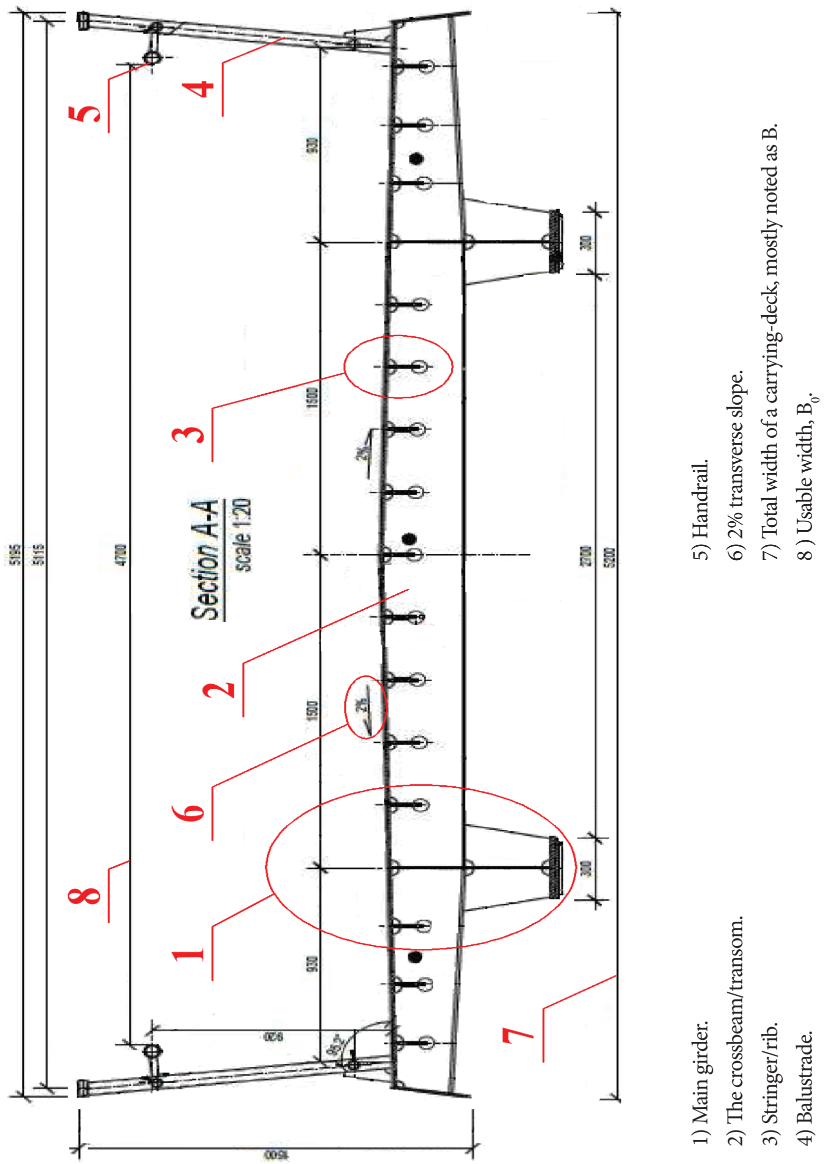
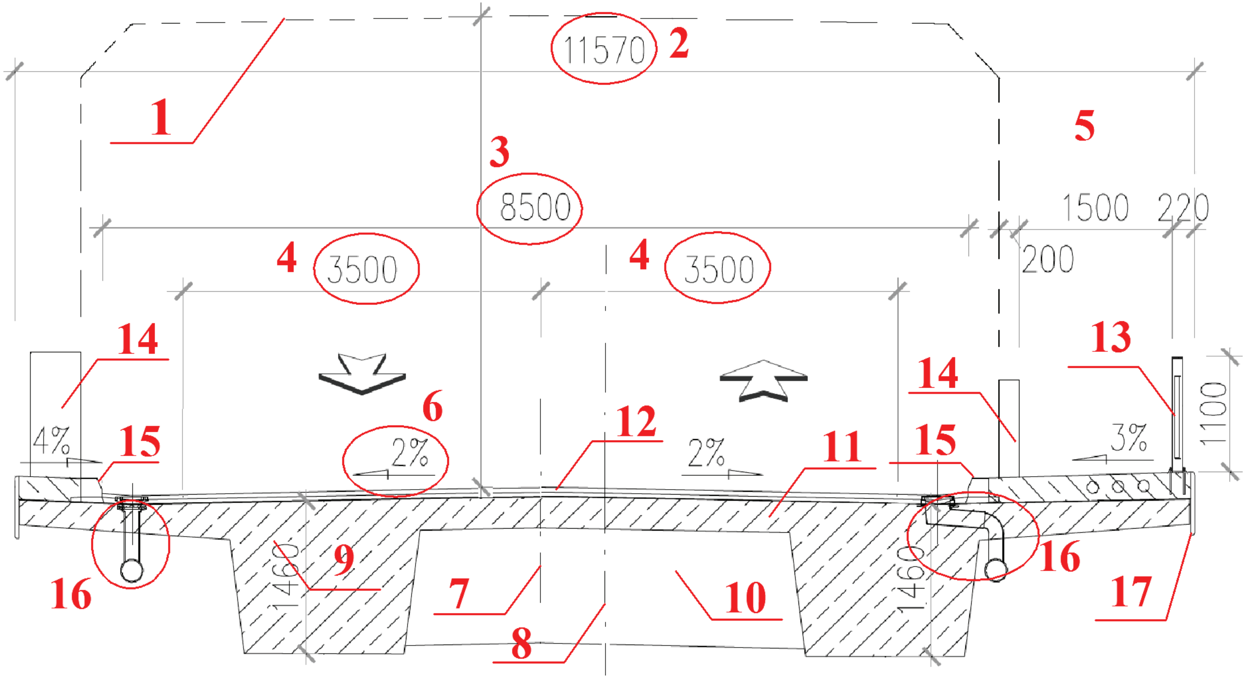



Figure 7.3. The cross-section in the middle of orthotropic steel footbridge




1) A road clearance gauge which in the case of motorways is 4.70 m high.
2) Width of the structure is B=11.57 m.
3) Usable area width for road traffic is B=8.5 m.
4) Width of a traffic lane is 3.5 m each.
5) One-side pavement - the clearance gauge in the case of 2 pedestrians is $B_p$=1.5 m.
6) Declines in the transverse are expressed in percentage.
7) Road axis.
8) Structure axis.
9) Main girder.
10) Crossbar.
11) RC plate of the deck.
12) Pavement layers. The bottom layer: hydro-isolation.
13) Pedestrian balustrade.
14) Traffic barrier.
15) A curb: in the case of bridges, curbs should be made of natural stone.
16) Plastic pipes of the drainage system.
17) Cornice shield.

Figure 7.4. The cross-section of a RC or prestressed monolithic road bridge [129]

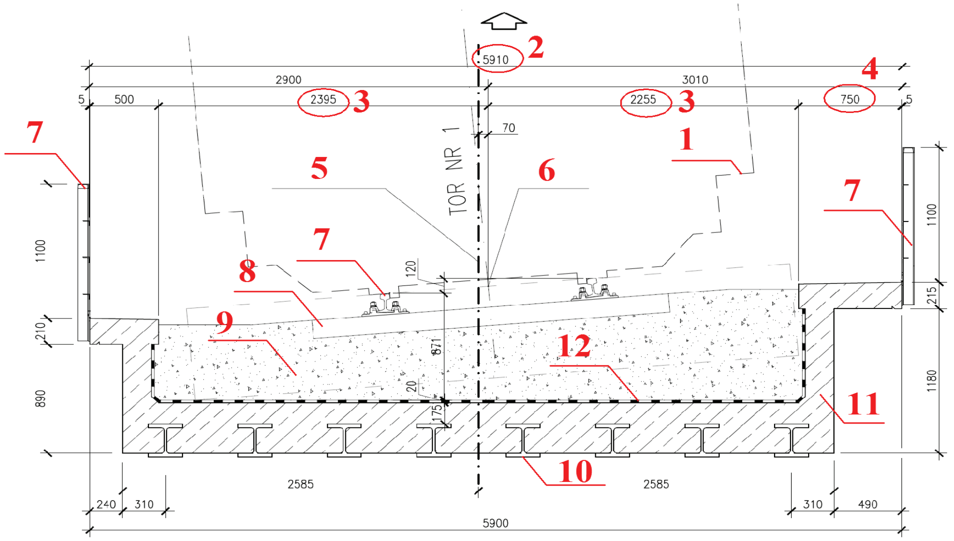



Figure 7.5. The cross-section of a railway bridge located on the stretch of railway track in a horizontal arc [129]

1) The line which limits the railway clearance gauge, a fragment.
2) The width of the bridge, B=5.91 m.
3) Usable width $B_0$=3.395+2.255=5.65 m.
4) One-side pavement, the clearance gauge width for 1 pedestrian $B_p$=0.75 m.
5) Axis of the bridge.
6) Axis of the rail track.
7) Pedestrian balustrade.
8) Tie.
9) Crushed stone foundation.
10) Steel I-beam.
11) RC chest of the ballast trough.
12) Hydro-isolation.

Note . 10) and 11) form the structure known as a filler which is a variant of the composite of steel-concrete bridge; see: EN 1994-2, 5.5.3 Classification of sections of filler beam decks for bridges.

## Composite bridge of steel and concrete

In a composite bridge of steel and concrete tension is taken by the bottom flange of steel plate-girder of the carrying deck while the concrete plate is compressed. Both elements i.e. the steel girder and the concrete slab are joined by headed studs. This system has some additional technological advantages as it combines the advantages of steel and concrete bridges.

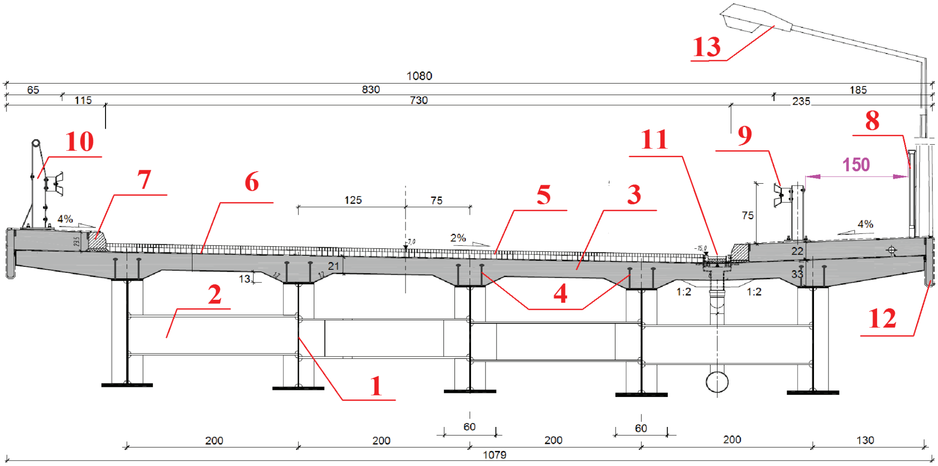



Figure 7.5. The cross-section of composite highway bridge [129]

1) A steel plate-girder consisting of the bottom flange 600x40 mm, a web of the thickness of 8 to 12 mm and the upper flange 200x20 m. Girders are usually made of welded plates. The height is 1/15 of the bridge span L.
2) Crossbar – crossbars are mostly made of HEB profiles.
3) Concrete (RC) plate/slab of the thickness at 20 cm.
4) Headed stud connectors.
5) Two bituminous pavement layers.
6) Hydro-isolation at the bottom.
7) Stone or, possibly, concrete curb.
8) Pedestrian balustrade.
9) Traffic barrier.
10) External barrier.
11) Drainage groove.
12) Cornice shield.
13) Lantern.

*45*

**Access wharf.** A composite superstructure under construction. The carrying element consists of two continuous tandems of steel plate-girders. The shape of the massive concrete pillars shape allows for an inspection by a trolly that moves between the columns.

## Bridge longitudinal-section

A longitudinal section is a component of bridge *Main Drawing*. It is a result of the cut along the grade line or the longitudinal symmetry axis. It displays structural elements of a bridge and road/rail elements as well as other facilities.

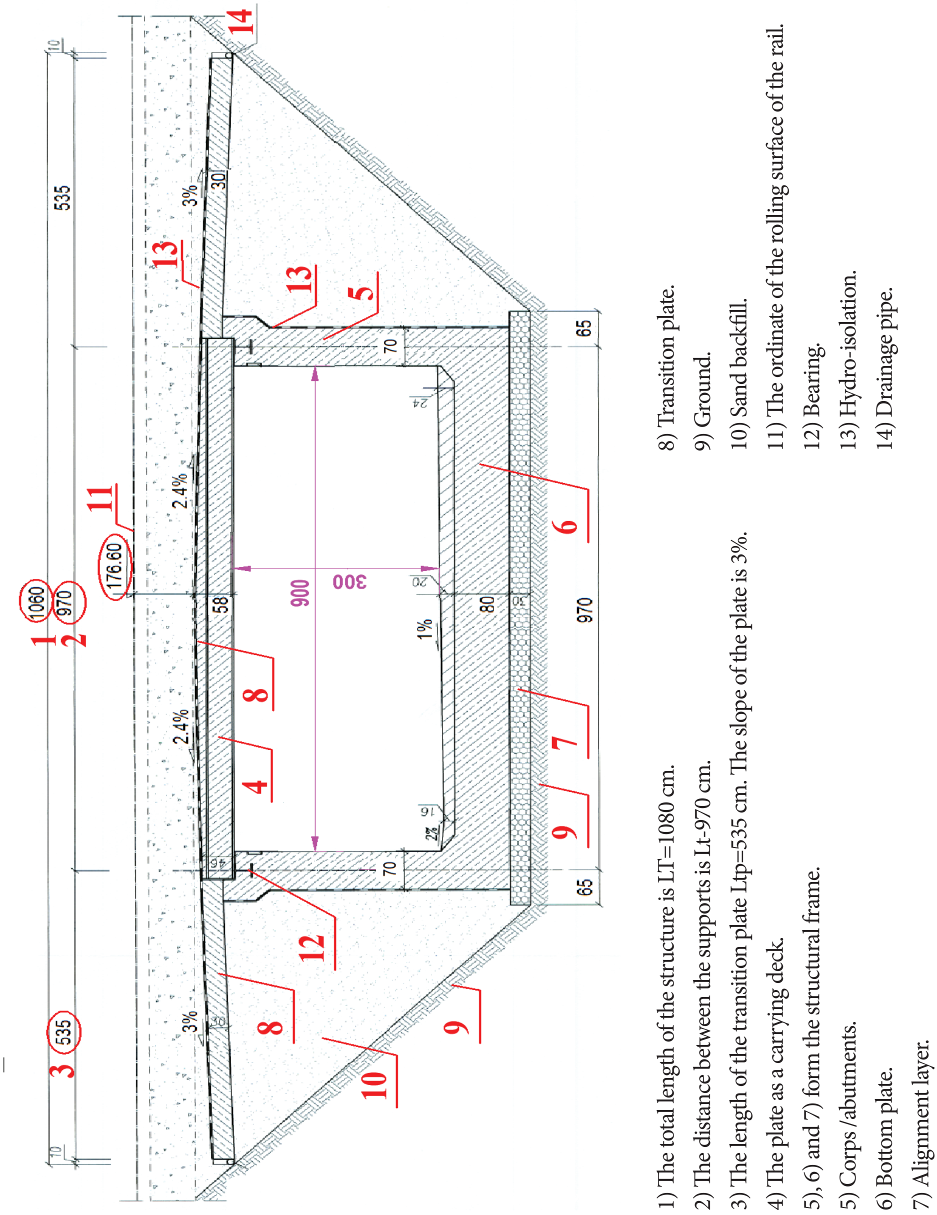
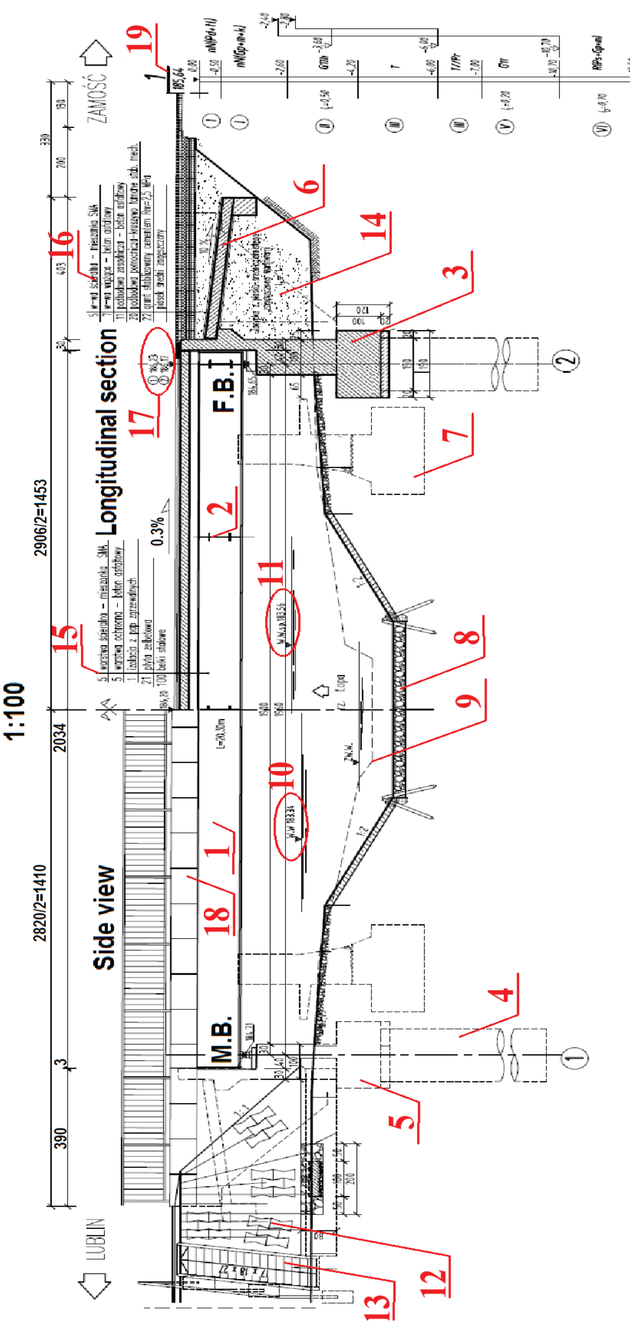



Figure 7.5. The longitudinal section of concrete (RC) railway culvert [129]

The clearance gauge/light of the culvert is a rectangular area of 300x900 cm.




1) Steel welded plate girder.
2) Transom/cross-beam of HEB type.
3) Abutment.
4) Piles of a large diameter.
5) Cap of piles.
6) Transient plate.
7) Residues of previous abutments.
8) Strengthening of the river bottom - a designed riverbed.
9) Previous riverbed shape.
10) High water level ordinate.
11) Dammed water level ordinate.
12) Strengthening of the slope of the cone.
13) Maintenance stairs.
14) Sand backfill.
15) Description of the pavement layers on the bridge.
16) Description of the pavement layers on the approach to the bridge.
17) Ordinates on the gradeline axis.
18) Cornice prefabricated shields.
19) Geotechnical borehole no. 1.

Figure 7.6. The longitudinal section of composite bridge in Lopiennik

F.B., M.B. mean a fixed bearing and a movable bearing respectively. A fixed bearing is placed on the lower abutment.

Figure 7.7. The side view of composite bridge in Lopiennik *(by SLK)*

Fig. 7.7. shows the importance of horizontal lines in a bridge from the aesthetic point of view. They repeat the edge lines of the top and bottom lines of the railings for pedestrians, the lower and upper edge lines of the cornice and the bottom line of the bottom flange of the steel girder. Their mutual distances, their length, the colour of these elements create the image of the bridge. In the discussed case we can talk about harmony, synergy and the pleasure of looking at the bridge from a side. These features allow the bridge to fit into its natural meadow surroundings. Moreover, the bridge has been designed according to the ecological criteria. This is an example of an ordinary, but pretty bridge.

## *Bearings*

Bearings are elements which transmit local pressure caused by girders onto abutments/pillars. They can have different forms and can be made of various materials, such as cast steel, steel, neoprene or concrete. In an extreme situation, a plain strip of bituminous roofing can function as a bearing in the case of a plate superstructure. Nevertheless, modern bearings have a complex structure combining steel members of congruent curvatures and PTFE spacers. In any case, to cut a long story short, the bearing consists of an upper plate, a bottom plate and an articulated element between them.

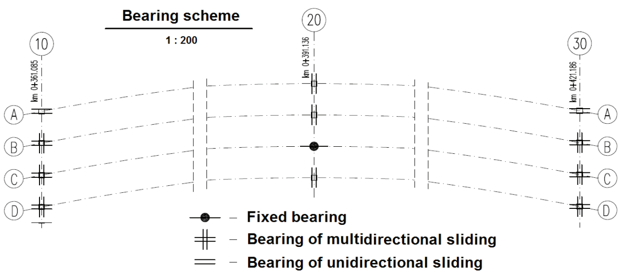
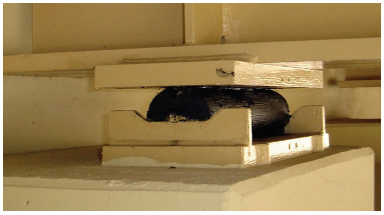



Figure 7.8. The example of bearing in case of three span road bridge [129]

46 

**Roller bearing.** The movable steel bearing consists of a bottom plate with a travel stopper, a roller as an articulation, a simple upper plate. The black colour of a roller comes from the graphite lubricant.

47 

**Fixed articulated bearing.** The fixed bearing consists of a bottom plate in the form of a steel strip with a 1 cm high hummock and an upper plate.Steel bearings are simple, inexpensive and very reliable.

48 

**Fixed articulated bearing.** A fixed and articulated bearing of a 50 m long railway truss bridge.

49 

**Movable bearing.** A movable bearing of two rollers. A railway bridge.

50 

**Bearing corrosion.** A typical roller bearing works properly. However, in this case the corrosion of concrete at the end of the beam has resulted in the limit state on the extreme support.

51 

**Sherical bearings.** The storage of modern steel-neoprene bearings for a large bridge. Between steel spherical members the PTFE strips are placed. Also in this case one can distinguish the bottom and upper plates as well as the bearing element.

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Review excerpt:

*The monograph can be considered as a reliable handbook familiarizing constructors with the issue of road and bridge structure aesthetics. The presented problems are discussed matter-of-factly and clearly with the emphasis on the harmony between the object and its surroundings as well as the importance of right proportions. Introduced concepts are explained intelligibly. The authors underline the necessity of the co-existence of visual (aesthetic) and technical aspects which ensure both the attractiveness of objects and their long and comfortable use.*

*The work describes numerous valuable concepts, such as harmony and proportions, that should be taken into consideration when designing. Apart from these – also interdisciplinary concepts, related to art, philosophy and history (e.g. the history of beauty). Furthermore, the authors take a close look at technical-structural issues, regarding, among others, the choice of a static scheme or the shaping of abutments, piers and pylons. They also discuss in a more detailed way suspension bridges as an icon of their times. Certainly, both the interdisciplinary part and the more technical aspect will come in handy for designers and in particular for future designers.*

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