SUSTAINABLE DEVELOPMENT IN ENGINEERING STRUCTURES

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Summary

Engineering structures belong to expensive structures with a long service life. They may be designed and constructed so that they satisfy the criteria of sustainability. The comments on the requirements on structures and on their service life are presented. Two examples show how the sustainability was achieved. The possibilities of future sustainable building are briefly outlined.

Keywords: Engineering structures, load carrying systems, architectural appearance, construction, service life, durability, maintenance, costs.

1 Introduction

Already 30–40 years ago people realized that the development of the society, which is faster and faster, should not load future generations. One of the definitions of the sustainable development reads as follows:"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It means that our development must be conditioned by limits of exhausting natural sources, by limits on pollution of environment, and by many other requirements. The sustainability is closely associated with maintenance, durability and service life of structures.

2 Requirements on structures

The structures have to satisfy a wide range of criteria. The usual design criteria like safety, serviceability, durability, etc. are given in the design codes. These could be called technical and they are essential for safety and reliable function of the structure. The technological criteria guarantee that the structure may be erected reliably, in an adequate time according to the requirements of the design. The technological and technical criteria interact very closely at engineering structures in particular. Requirements on economy are very essential and limiting in many cases. The clients often ask for the costs for erection of the structure. It is well known that such costs are only part of the total costs and also the maintenance, repairs, exchange of some parts, and finally demolition should be also taken into account. The total costs should be estimated when evaluating the design alternatives. Such costs may be calculated on the basis of estimated service life of the structure. There are many other criteria which are also rather important. Aesthetics is very important at engineering structures like bridges. Environmental requirements have to control the consequences of the structure on the surroundings, CO_2 emissions and other impacts. If all the groups of requirements are satisfied, the structure may be considered as technically efficient, economical, with low impact to the environment and then it can be expected that it can be also sustainable.

3 Service life of structures

The design service life is designed according to the codes. The European codes assume the service life of buildings about 50 years, the service life of important engineering structures in the range 100 to 120 years. However, there is a number of structures, which serve for much longer time, several hundreds or even thousands years. It should be also expected that modern structures will be used for much longer time than their expected service life. The value of existing structures is rather high. Assuming that they will be used only for the period of the design service life would require such investments, which are not realistic [1]. The longer service life should be therefore considered in the design, although it is not assumed in design codes. As an example, there is a statistics of bridges in the Czech Republic. From the total number of investigated bridges 17 113, only about 15 % are in excellent state, while almost 30 % are only in satisfactory state and almost 17% are in a bad state [2]. Most of them are in service much longer than it was expected. Although their state in not good, they must be used and cannot be repaired since the financial funds are limited. The longer service life than that originally assumed would be very welcome, however, in most of cases the bridges suffer from significant damages, and their loading capacity had to be reduced.

4 Examples of sustainable engineering structures

Engineering structures belong to the group of structures with the longest service life. Great attention should be paid to their design and construction. The design of details is essential for their durability.

4.1 Immersed subway tunnels

The two tunnel tubes of the subway line C in Prague cross the Vltava River. They are located very close under the river bed. The width of the river is about 200 m. The concrete tunnels were planned to be built by the classical way in three large cofferdams in the river. Such construction would be rather costly and time consuming. The insufficient construction time and other reasons led to the modification of the construction process. It was modified and the tunnel tube was cast in the dry dock on the river bank. After flooding of the dry dock, the tunnel tube was launched into the trench excavated in the river bed where it was supported. The process was repeated for the second tunnel tube [3]. The modification of the construction process led to substantial savings of the works in the river and the river banks were disturbed only in a very limited extent. The construction time was significantly shorter. The high quality of the watertight tunnel structure without membrane waterproofing was achieved, which guarantees long term durability of the structure with a very limited maintenance. Last but not least the risk of damages due to the high water level during construction was significantly reduced. It is necessary to note that the high flood came just after launching of the second tunnel tube in 2002.

4.2 Bridge over the Oparno valley

Arch bridge over the Oparno valley is situated on the motorway D8 from Prague to Dresden. It is located in the protected natural area. The arch bridge was selected because of the architectural reasons and good fit into the landscape. The two independent almost identical bridges were built, each for one direction of the traffic. The span of the arches is 135 m, which is the second largest span of the concrete arch in the Czech Republic. Prior to construction, the design was modified, the better quality of concrete was used for construction [4]. The dimensions mainly of the arch, of the piers and of the bridge deck could be reduced significantly. The total reduction of about 22 % of concrete consumption represented savings of 780 t of cement, which is about 15 % reduction of CO_2 emissions. The bridge has efficient structural system with stable and durable arch bearing system. The cantilever construction with temporary stays was chosen in order to save the environment in a protected natural area (Fig. 1). The bridge fits well into the environment. The maintenance is reduced since the bridge is a semi-integral structure. The increased concrete strength of concrete contributes to durability of the bridge.

Fig. 1 *Bridge over the Oparno valley*

Fig. 2 *Sunniberg Bridge*

5 Sustainability of future engineering structures

The examples shown in the previous section show that there are several possibilities how to build structures which satisfy at least some of the criteria of sustainable development. The three groups of advanced development may be applied: i) Application of advanced materials, ii) efficient structural systems and iii) erection by an appropriate construction technology.

Ultra high performance concrete (UHPC) may be taken as an example of the advanced material which efficiently combines important properties for sustainable development. High strength and contemporarily extreme resistance against environmental impacts resulting in extreme durability allow for construction of light structures with long service life and reduced maintenance [5]. Bridges with the deck made of UHPC do not need waterproofing and in some cases the traffic may run directly on the concrete structure. Although the costs of UHPC are rather high, due to its composition and due to the extremely complex technology of production, the favourable properties of UHPC promise wide range of applications and contemporarily a contribution to sustainable development.

The efficient structural system of an engineering structure leads to economical structures in terms of consumption of materials. The Sunniberg Bridge (at Klosters in

Switzerland, designed by Christian Menn) is a nice example of a sustainable structure. The road bridge has a very slender bridge deck suspended on light frame piers (Fig. 2). External longitudinal prestressing interacts with stays. The bridge has 5 spans and the total length 526 m. The main span is 140 m long. The bridge is horizontally curved which allowed for elimination of bearings and expansion joints. The structure is an integral bridge. The maintenance is significantly reduced.

The new trend in past years is building of integral and semi-integral bridges. The idea is not so new. Already 100 years ago Hennebique designed the Risorgimento Bridge in Rome with the span 100 m. The bridge is fixed into the abutments without bearings. The bridge in spite of its age is quite modern with minimum maintenance. Now even long viaducts are designed as integral or semi-integral structures. Scherkondetal Bridge is a railway bridge built recently in Germany. The bridge is a frame structure made of prestressed concrete (576 m long) with a typical span length 44 m. The stiffnesses of the bridge deck and of the piers and foundations are well balanced; the bearings are located only at the abutments. The structure is very efficient and requires minimum maintenance. The bridge received the German Bridge Construction Price 2012.

6 Conclusions

Engineering structures may be designed so that they satisfy the requirements of the sustainable development. The new materials, advanced technologies and innovations in design provide space for savings of materials, natural sources and energy. The design of details is essential for their durability. The particular attention should be paid to the service life of concrete structures. The design service life assumed in the design codes seems to be too short.

Acknowledgement

The results presented in the paper were partially supported by the Ministry of Industry and Trade of the Czech Republic (project No. FR TI3/531).

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