Sustainable Design and Maintenance of Concrete Structures

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Summary

Concrete is an environment-friendly material. Approximately 85-90% of concrete comes from natural resources, which normally are available in extensive amounts. Concrete is durable and may, if the structure needs to be demolished, be recycled as aggregates in new concrete. The sustainability of concrete structures may be further improved by minimising the use of resources, i.e. by using more environment-friendly constituent materials without having to compromise on durability and by optimising the structural design with regard to both utilisation of load bearing capacity and to service life.

Keywords: Sustainable, environment-friendly, life cycle inventory, concrete, design, maintenance, repair

1. Introduction

This paper is based on two development projects, one on structural design and one on maintenance and repair. The projects are part of a four year contract, initiated in the second part of 1998. The contract is called "Resource Saving Concrete Structures" (colloquially "Green Concrete").

The evaluation of selected structural designs as well as methods for maintenance and repair will include life cycle inventories (LCI). For the evaluation, requirements to acceptable combinations of measurable values will be set up. Based on structural calculations amounts of materials for the various structural designs will be determined and used to estimate the design related environmental loading, and - including information about the service life and the need for maintenance - to estimate the operation and maintenance related environmental loading.

2. Structural Design

The purpose is to develop structural designs which

- Minimise the environmental effects from the construction of concrete structures
- Optimise - and increase - the use of environment-friendly concrete types

Motorway bridges have been selected as the type of structure to be dealt with. The project constitutes the following activities:

- Identification of significant technical, environmental, and financial factors
- Proposal of alternative structural designs
- Evaluation of selected structural designs with regard to
  - constructability and durability
  - environmental effects
  - structural and financial effects
- Preparation of catalogues on
  - environment-friendly structural designs
  - structural designs for environment-friendly concrete

As part of the contract, a "demo-bridge" will be constructed. It is roadway birdge, and it will be designed according to the Danish rules and regulations for loads and dimensions. The purpose of evaluating alternative bridge designs and alternative design details is to:

- Minimise the amount of materials by
  - changing the design (increase the degree of utilisation of the load bearing capacity)
  - using alternative materials, e.g. concrete with very high compressive and tensile strengths (compact reinforced concrete (CRC [2])
- Maximise the service life
- Substitute the currently used materials by more environmental-friendly materials
- Increase the use of prefabricated structural elements (optimised production)

3. Operation and Maintenance

Concrete structures in aggressive and extra aggressive environmental exposure, e.g. bridges in marine environment or exposed to de-icing salt, require maintenance, whereas concrete structures in passive environmental exposure have merely no need for maintenance. Based on this the following concrete types and structural elements have been selected for evaluation of maintenance requirements, both with regard to financial and environmental considerations:

- Type of structure
  - typical motorway bridge in concrete
- Type of concrete
  - concrete for aggressive environmental exposure
  - concrete for extra aggressive environmental exposure
- Structural elements:
  - columns
  - edge beams
  - bridge deck (with and without water proofing membrane).

To estimate of the environmental loading during the operation and maintenance phase, the impact of normal maintenance activities as well as repair activities will be considered. During the coming two years, information about the durability of environment-friendly concrete types and the environmental impact and service life of remedial measures will be collected. Based on the outcome of the life cycle inventories, suitable maintenance and repair methods will be proposed.

Developments in Structural Form to Minimise Environmental Impact

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Summary

Long span 'lightweight' structural forms employ low embodied energy because of direct force transfer. They can also create naturally light environments without the requirement for large amounts of non renewable energy for heating and cooling. They can form sustainable and delightful architectural spaces complementary to the existing rural or urban context with a minimum of environmental burden.

Abstract

In the light of the Rio Janeiro 1992 summit, architectural structures, even more then before, still need to be beautiful, comfortable and functional if they are to be sustainable and yet their construction depletes natural resources by embodying energy and their operation can consume non-renewable energy. Both have bi-products which increase the burden on the planet.

Structures which by their form carry their loads principally by direct compression or tension, offer the opportunity of minimum embodied energy. Indeed conscious choice of their form can facilitate natural ventilation and the use of transparency, translucency and reflectivity of structural membranes provides opportunities for natural lighting.

The techniques of form finding and analysis for air supported structures tents and cable nets, gridshells, stone vaults and shells have developed in the past 20 years from largely geometric or physical model, through to finite elements to real time modelling. Documentation for construction has improved from largely draft and drawn instruments to CAD and CIM delivery. The use of robotics for their construction is also now a possibility.

In tensile structures, improvements in microprocessing of form finding and analysis and patterning allow the detailed study of surfaces underload leading to flatter structural surfaces as at RSSB and for the Millennium Dome at Greenwich UK. This has been accompanied by Technical advances in the specification of the physical characteristics of modern tensile membranes. Most recently the use of foil cushions has provided light, transparent, insulating roof surfaces as at Eastleigh Tennis Club, Hampshire UK and other similar projects, providing the opportunity of the admittance of a full spectrum of solar radiation into the proposed enclosure.

Even hi-tech structural membranes need a primary structure for support for spans beyond 16-20 metres. The radial cable structure for the 320 Ø Dome at Greenwich and its 12 100m high masts embody 15kg/m^2 of structural and 1.5kg/m^2 of structural membrane in providing a 'naturally' assisted ventilation scheme within the 80,000m^2 translucent envelope.

Timber Grid shells offer the opportunity of engineering 'free form shell roofs' with little embodied energy. Following the exemplar of Mannheim Grid shell (1975), the grid shells at the Earth Centre at Doncaster, and for the Weald & Downland Museum use of single and double head shells respectively to create enclosed space. One is primarily sculptured the other for a naturally empered workshop for the repair of historical timber trusses.

Once again CAD-CIM techniques are enabling the construction of major vaulted forms in steel, glass and reinforced concrete. The conoidal vault spanning a maximum of 21m over the Maths Centre for Cambridge UK is a composite construction of prefabricated structural steel plate girders and beams encased in reinforced concrete to support a turfed roof of what is an elevated garden. The banquet hall for the Al Faisaliah complex has a number of wishbone shaped arches and r.c. beams to cover 63 x 81m space beneath the landscaped plaza. This provides both an expression of the architecture and the conduit for ventilation and lighting strategies.

Currently 43000m^2 of uninterrupted 3D flowing reinforced concrete shell forms on 33 1.5 x 3.02 piers is being design to create the naturally lit new Hauptbahnhof for Stuttgart, Germany. The platforms are located 12m below the historic Schlossgarten, right in the centre of Stuttgart adjacent to below and parallel to the existing listed Bonatzbau.

The paper has been written to stimulate continuing evolution of lightweight and longspan structural forms resulting from research at University of Bath, and elsewhere and from a number of projects currently being designed by Buro Happold as engineers with a wide range of international designers and constructors.

Indigenous Solar Electricity Generation

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Abstract

Energy is the key to development. Many developing countries suffer from lack of energy resulting in deforestation, poverty and population increase, a vicious circle. At the same time these countries usually have ample sun and arid "useless" land. This calls for solar power plants which they can afford with their own resources which are their skillful hands, sun and sand.

The Solar Chimney (as described earlier e. g. in SEI Vol. 4, No. 2, May 1994) fulfills these requirements, because it consists predominantly of a large vertical concrete tube and a flat glass roof.

Concrete/cement and glass are nothing but sand/stone and energy and labour, the energy being supplied by the first solar chimney itself, which thereafter reproduces indigenously.

In the paper the design of a 200 MW-solar chimney with storage for a 24 h continuous electricity generation will be described. By referring to the author's experience with bridge construction in developing countries*) it will be shown that these countries are very well able to build such large plants on their own.

Further, there will be a passing reference to the state-of-the-art in solar electricity generation including the author's own Dish/Stirling-systems for high efficiency decentral small scale solar electricity generation.

In conclusion it will be claimed that in the future developing countries could produce solar electricity not only to cover their own demand, but also for export for the benefit of the industrialised countries as well.

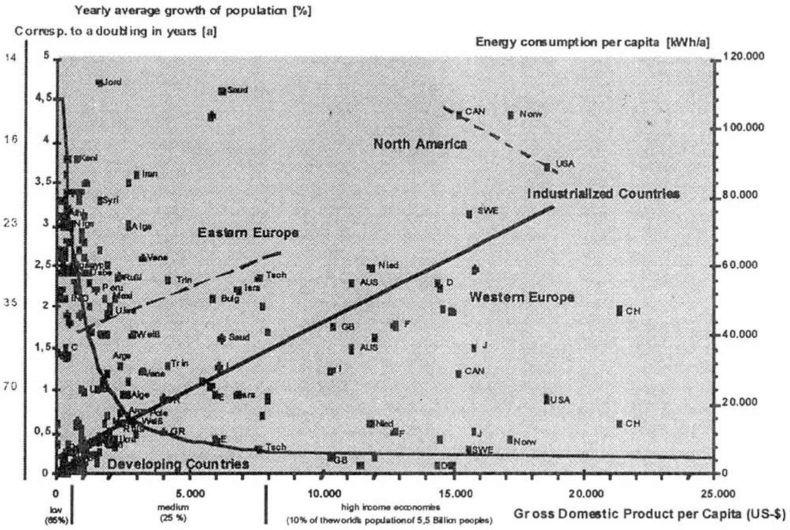

Fig. 1 Energy consumption and population growth in a country as a function of its per capita gross domestic product

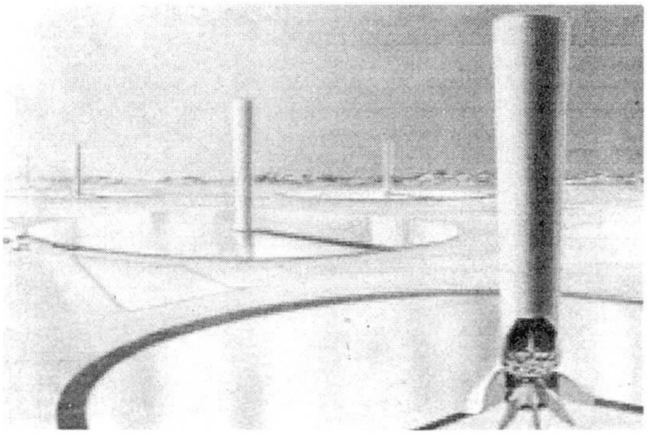

Fig. 2 Drawing of several large (100 – 200 MW solar chimneys in a desert

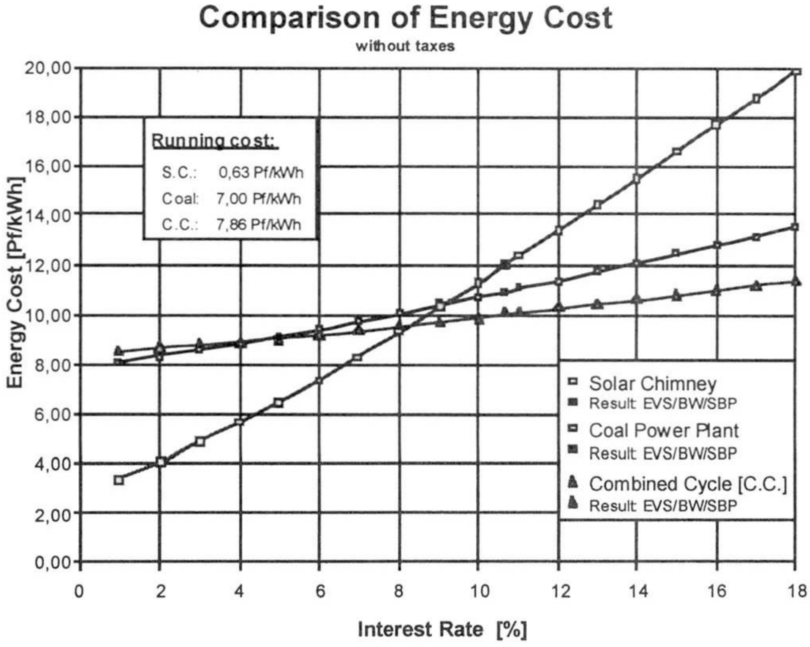

Fig. 3 Electricity costs from solar chimney, coal or combined cycle power plants depending on interest rate

A Step towards Sustainability through Underground Space Utilisation

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Summary

Building underground is becoming an important territory of a modern city. It has a potential to improve our urban environment by relieving pressure from the surface, developing better public-transport network, reducing noise and improving air quality, leaving more green areas in city centre intact and reducing distances by better concentration of functions. All of these aspects seem to be a characteristic of a sustainable city. On one hand, the sustainability of these structures is essential due to high construction costs. On the other hand, these spaces should provide enough flexibility for our ever-changing society and be able to satisfy the needs of the future generations. Therefore, these spaces deserve more attention from urban planners, architects and engineers due to specific requirements regarding both planning and design in order to improve the quality of underground spaces.

Keywords: sustainability; flexibility; planning; design; building underground.

Abstract

It is not possible to discuss sustainability without explaining the meaning of the word. In this context, that will say related to the built environment, a following definition of sustainable development can be given:
Sustainable development is such development that through its planning provides such design solutions that will assure a continuous exploitation in the future with respect to the existing ecosystem.
The four apparent keywords in this definition are planning, design, exploitation and ecological responsibility. The hidden words of this definition are lifestyle change and technological development.
On the example of underground designs it will be explained how at the same time different issues related to the sustainability can be addressed. Like for example:

- Problem with infrastructure and mobility in the cities
- Panning and design of underground spaces for the future

1. The Indoor City Of Montreal (Canada)

City of Montreal is an example where the underground transport system was successfully combined with other public functions. On one side, the realisation of Montreal's underground was made possible through well-defined financing scheme, where both the government and the private investors contributed financially to the realisation of the indoor city. On the other hand, such underground was only possible due to parallel and integrated planning and realisation of above ground buildings and underground spaces, since this significantly reduced the investment costs.

It is possible to plan and realise underground spaces and yet provide such design that would make it possible to realise above ground buildings later on. Such planning is very flexible and open for future needs and requirements and at the same time intensifies land exploitation in urban areas.

2. Building Today and Planning for the Future – Rijswijk (The Netherlands)

The existing railway was a barrier in every sense: a visual, physical and psychological barrier. Once, this railway was designed on the edge of the city, but due to extensive development after II WW the city expanded on the other side of the tracks as well, and since then the tracks formed an obstacle for continuous city development. When the Dutch Railway Company decided to increase the capacity and double number of tracks, the municipality of Rijswijk favoured the underground solution. This intervention not only improved the quality of life in the surrounding area and connected the two city parts, but it also gave the possibility for new developments and intensification of the land use above the underground tunnel. It also shows the possibility of having very frequent traffic flow and an important, not only local, but regional infrastructure through the city, which still does not obstruct the daily activities in that area.
In such way, the present needs were met but also a step was made towards the future and possible new requirements. This was done in the following way. By placing railway underground a free space emerged, which planners saw as a chance to create extra green areas in combination with apartment and office building. A part of that area is used at the moment as a park and children's playground, with a possibility to realise buildings above the underground tunnel in the later stage. This was made possible with the realisation, since having in mind that in the future there may be a need to build above the tunnel some columns were reinforced to be able to take over the extra load. At the moment already two buildings are realised above the tunnel: one is an apartment and the other is an office building. In the future it is possible to realise more buildings above the tunnel.

3. Conclusion

Building underground is not an answer fcr all problems, but it can be a very significant part of sustainable city. Two examples that were explained show that the underground spaces have a huge potential in cities where mobility is essential and land precious to be wasted. They also show the importance of integrated planning of above and underground spaces (Montreal) and the possibility to realise plan in time sequence, depending on requirements (Rijswijk). In other words, utilisation of underground spaces is an important step towards achieving more sustainable urban environment.

Sustainable Engineering: Tools and Aids

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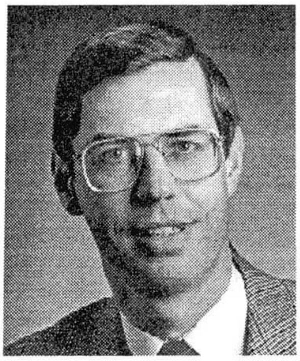

Arie Reij, born in 1947, has a master's degree in civil engineering from Delft University of Technology. He worked in research at TNO and joined Rijkswaterstaat in 1983. After occupying various functions, both in research and management, he was appointed head of the Policy Analysis Section of the Civil Engineering Division of Rijkswaterstaat in 1991.

Summary

In this abstract, I discuss the approach towards sustainable construction in the Netherlands in general and at the Directorate-General for Public Works and Water Management in particular, and then focus on sustainable engineering. The current situation in the field of road and waterway engineering is presented, highlighting the progress made so far and the major ongoing developments. An overview of the tools and aids available is given, paying particular attention to a recently developed method for expressing the environmental impact of a structure in terms of money.

Keywords: Sustainable building; environmental impact analysis; engineering; monetary analysis; design aids.

1. Introduction

Since 1990, a comprehensive programme regarding sustainability at Rijkswaterstaat has been running, aiming at an operationalization of the rather abstract notion "sustainable." The ultimate goal is for the topic to need no further special attention, because it is just as *natural* as cost reduction. The main issues that we have been focusing on are understanding of the topic, communication, and tools. Although the importance of an environmentally responsible engineering and construction practice is no longer questioned, choices for sustainable engineering are not straightforward. Therefore, instruments rather than instructions are required.

2. Tools and aids

If sustainable engineering ought to become common practice, sufficient tools and aids should be available. At Rijkswaterstaat, we defined the following items as "anchor points", suitable for daily practise: raw materials, waste, energy and space and external appearance. They are all of a qualitative nature. Projects where a particular item has been given special attention were awarded the status of "demo-project" as working examples for field workers.
Another broadly useful general aid is the sustainable building help desk we have set up, for passing questions through to specialists on specific topics. Internal to our Rijkswaterstaat organisation, we can provide project teams, with so-called "sustainable building consultants".

Targets were stated in order to get better results and enabling to make the right decision in the face of various options. For energy conservation at Rijkswaterstaat a "company target" of minus 20% within 12 years has been stated. For the designer, we have developed a "Guide for energy-lean design of civil engineering installations" to tackle technical problems.

To assist the designer and the contractor in achieving a sustainable structure in the Netherlands, a number of packages of standard measures and preferred options have been developed, having a similar structure; the core consists of a number of measures that can be taken. They serve the purpose to obtaining a minimum level of sustainability by measures that all relevant parties have agreed upon. The ultimate goal is to specify so-called "durability performance requirements".

3. Monetary evaluation

As to respond to the increasing demand to quantify the environmental performance of structures, a study to "develop a method that would enable a designer to assess the environmental impact of a structure, in such a way that it can assist in making the right design decisions" was carried out by the Dutch Organisation for Applied Scientific Research (TNO).
An initial survey reveiled that various methods already exist. These are mostly based on the outcome of an Environmental Impact Analysis (EIA), that is highly standardised, at least in the Netherlands, and thus appeared to be a sound basis for further development. A number of methods showed sufficient potential to justify further examination, among others "eco-indicator" ("Eco-Punkten") and Building Environmental Diagnosis System (BEDS). However, due to various reasons these were considered inappropriate for applying on building structures.
A decision had to be made as to what sort of quantification would be used. Expressing things in money has clear advantages, such as the connection to the normal monetary evaluation of projects, opportunities for optimisation and possibilities to calculate the environmental efficiency. A method was developed with the aid of a pilot structure (design "Second Stichtse Brug", Netherlands) that served as test case and data source. This is a high-strength concrete box-girder bridge with a length of 320m and a main span of 160m. For the study, the design freedom was limited to the choice of materials, so no alternative construction methods or locations were taken into account. The environmental impact is expressed in the magnitude of aspects (following from an EIA) that have an effect on the environment, with the limitation that only the materials necessary for construction were taken into account, as other data were unavailable.
For the next step, to express the derived quantities in terms of cost or money, various methods are available, so no new method needs to be developed. One could look at the damage that is caused to the environment, but it could also be evaluated by the prevention or substitution cost.
A choice was made to valuate all different environmental effects individually, and not to add them up first in an arbitrary way, and then to multiply by unit environmental cost, as is done in e.g. Greencalc.

4. Concluding remarks

The pilot application showed that a monetary evaluation of environmental aspects is possible. It also demonstrated that the energy content might be used as a practical measure for the environmental impact of structures. However, because of limitations of the pilot, further research is needed to establish the latter conclusion.
For a more widespread application of this method, a number of requirements have to be fulfilled: A reliable and up to date databases with standardised environmental data on materials and processes is necessary, the method (esp. EIA) should become less time consuming, and the acceptance of a monetary valuation of environmental aspects should increase. Not to replace other, more subjective or emotional, valuations, but as an aid to optimising the environmental performance of building structures.

In my view, there is a remarkable resemblance between the project budget in real money and in "environmental" money. Both reflect a certain boundary condition for the project. Both give an opportunity for optimising the performance at equal or lower cost. And both will never be the sole criterion for a final decision.
I feel that the environment could benefit a lot by a more comprehensive analysis of the environmental impact of structures, particularly such long-lasting structures as bridges, tunnels, and waterworks. Monetary valuation of these affects could help to reduce them, even, or perhaps especially, if this would require more "ordinary" money.

Future Trends in Design and Maintenance of Structures

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Summary

Whilst globally governments are coming to terms with the need for sustainable development, this still has to translate and cascade through to practical policies and actions. When it does, it will impact and manifest in the design and management of structures. This is just beginning in the UK and this paper addresses some of the issues that are beginning to emerge and impact on bridge design and management. The paper looks particularly at the development by the UK, Highways Agency of a structures database around with sustainable maintenance strategies for the bridge stock can be developed.

Keywords: Sustainability, bridge management, design codes, structures database.

1. Introduction

The Kyoto Protocol of 1997 has led to the acceptance by most of the world's developed countries to a commitment of a 5.2% reduction in CO^2 emissions by 2010. This real target brought a new urgency to the debate about the major sustainable development challenges that confront construction. They include global issues such as resource depletion, protecting bio-diversity and climate change. The processes and potential impacts are not yet well understood but as knowledge advances the implications for design and management of existing and future buildings, infrastructure and communities will need to be addressed. This paper addresses some of the issues that will need to be addressed in the design and management of bridges. It particularly looks at the development in the UK of the Highways Agency's Structures Management Information System (SMIS), which will support the development of a sustainable management strategy for the Highways Agency's 15,000 structures including bridges.

2. What is "Sustainability"?

The UK Government's vision of sustainable development is based on four broad objectives.

- Maintenance of high and stable levels of economic growth and development.
- Social progress which recognises the needs of everyone.
- Effective protection of the environment.
- Prudent use of natural resources.

The objectives need to be translated through policies and practically applied to the built environment, including bridges. It will mean some changes to current thinking.

3. Bridge Design

Bridge design codes and standards have traditionally concerned themselves with safety and economy, embracing all aspects of techniques and materials. The every widening spectrum and increasing rate of change threatens to outstrip their usefulness and in future they may need to concern themselves only with the fundamental requirements, which will include sustainability as well as safety and economy. Engineers will use their skills and wealth of information becoming available to meet them. However, much more research and information on sustainability issues is needed.

Bridge owners and designers do not have the information or rationale to make optimum decisions. New techniques and developments to whole life costing and design life will be needed as well as radical changes in conceptual thinking. For future, sustainable, bridge design we can expect to see wider but more basic performance requirements, embracing sustainable issues coupled with component specific design lives to reflect future functional uncertainty and sustainable considerations.

4. Bridge Stock Management

Sustainable management should ensure that future generations will not face a costly and burdensome legacy from our activities of today. Such burdens can be environmental pollution, depletion of natural resources, as well as economical and logistical burdens.

There is a lot to do before it can be claimed that bridges are managed in a sustainable way. In the UK a structures database containing key information providing a high level review of the performance of network structures is seen as a fundamental building block and starting point, around which sustainable maintenance strategies for the bridge stock can be developed. Current performance indicators being developed seek to avoid future logistical and funding problems, but the system is being developed so that it can accommodate any change in values arising from issues of sustainability.

5. Conclusion

Engineers are just beginning to come to terms with sustainability and what this may mean for bridge design and management. The paper describes some of the issues that engineers may have to contend with and which may overturn conventional thinking. The paper also describes part of the development of the Highways Agency's future bridge management methodology aimed at addressing future sustainability needs. Many issues remain to be decided.