Concrete structures as a safe engineering response to environmental catastrophes

Concrete Structures as a Safe Engineering Response to Environmental Catastrophes

Structures en béton : réponse technologique sûre aux catastrophes écologiques

Betonstrukturen als sicherheitstechnische Antwort auf Umweltkatastrophen

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SUMMARY
Innovations must not be limited to the classical areas of concrete construction. As a matter of fact, they are needed in numerous new fields. One of these is the protection of the environment against catastrophes caused by technological failures. The article outlines the concept of a protective technology and of new concrete structures to guarantee a safe enclosure of raw materials, products and waste materials in an industrial cycle. The objective to be achieved is to strictly limit any damage caused by accidents.

RÉSUMÉ
Les innovations ne doivent pas se limiter aux domaines classiques d'utilisation du béton. Le besoin s'en fait sentir dans nombre de domaines nouveaux, en particulier celui de la protection de l'environnement contre les catastrophes d'origine technique. L'article expose les principes de base d'une technique de protection. Il indique selon quels principes les nouvelles structures en béton doivent être conçues en vue de constituer pour les matières premières, les produits ou les déchets impliqués dans le circuit industriel une enceinte offrant toutes garanties de sécurité. L'objectif visé est, quelle que soit la probabilité des accidents, de limiter strictement les dommages qui leur sont dûs.

ZUSAMMENFASSUNG
Innovationen dürfen sich nicht auf die klassischen Arbeitsgebiete des Betonbaus beschränken. Gefragt sind sie vielmehr auf zahlreichen neuen Gebieten. Dazu zählt der Schutz der Umwelt vor technikverursachten Katastrophen. Skizziert werden das Konzept einer Schutztechnik und neue Betonstrukturen zur Gewährleistung der sicheren Umschließung von Rohstoffen, Produkten und Abfallstoffen im industriellen Kreislauf. Ziel dabei ist es, unabhängig von der Wahrscheinlichkeit von Unfällen, den mit Unfällen verbundenen Schaden streng zu begrenzen.

1. INTRODUCTION

Modern industrial society has been thrown into a state of extreme uncertainty by spectacular cases of technological failures with catastrophic consequences. Names such as Seveso, Mexico City, Bhopal or Schweizerhalle - and last but not least Chernobyl - may be regarded as typical of this uncertainty. The consequence is that society welcomes a product but at the same time rejects the production process it involves. The public continues to expect general affluence and general safety. Affluence and safety are also political aims, as indeed they surely must be, but they can only be realized - if at all - by the continuing and increasing use of large-scale industrial technology. Any technology however has potential risks that may result in damage - indeed must do so at some time or other. Only a technology that we decide to do without it is devoid of any risks.

But even when the damage potential is catastrophically high, accidents need not necessarily result in disasters. This report aims to demonstrate this for a number of non-nuclear technologies and at the same time will attempt to answer the question: "How safe is safe enough?" It is based on development work carried out by Dyckerhoff & Widmann AG. Limitations of space do not allow a description of individual projects and the solutions found, but instead we will outline a preventive engineering concept for the entire industrial cycle: raw material, product, waste material, in which all these solutions are integrated and from which they were developed. What is technically feasible, and what is economically acceptable - both questions are dealt with here.

Applications of this kind for concrete construction are extremely new and constitute both an opportunity and a challenge.

2. MEXICO CITY AND BHOPAL - TWO CATASTROPHES

Most events with catastrophic consequences outside what may be termed "the industrial fence" - and this is what we mean by environmental disasters - have their origin in technical disturbances "inside the fence" which have got out of control.

In Mexico City, after a leakage in a PEMEX liquid gas plant, several explosions and devastating fires occurred, destroying the plant almost completely and devastating the surrounding housing estates. According to official figures more than 500 people were killed, with more than 7,000 seriously injured. Material damage is put at several hundred million US $. The area affected was 2.5 km in diameter.

In Bhopal, India, approximately 25 tons of highly toxic methylisocyanate were released from one of several storage tanks in a chemical factory belonging to Union Carbide. In this disaster about 3,000 people who came into contact with this toxic substance were killed, and about 200,000 suffered injuries to health. The amount of subsequent damage is incalculable. Lethal levels of poisonous gas were exceeded over an area of 40 km^2, with a diameter of approximately 7 km. India demanded more than US $ 3 billion compensation from Union Carbide for damage to property, health and environment.

3. SAFETY AIMS AND SAFETY MEASURES

Catastrophes are "infrequent events" - cases of technical failure with extreme consequences, as shown by the disasters of Mexico City and Bhopal, but the probability of their occurrence is really small. In the risk spectrum these are represented by the dark curves (Figure 1). A risk is usually defined as the product of the probability of occurrence and the potential amount of damage. Below a limit delineated by the relevant practical experience all indications of probability have a purely hypothetical character. For facilities involving a high level of risk - these are the ones we are dealing with - there is a gap between the reliability factor obtained by calculations and that dependent on operational experience. This gap can never be closed, however exact our calculations. Chernobyl has once again brought home this fact.

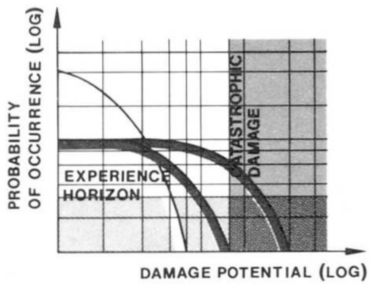

Fig. 1. Risk spectrum

The necessary conclusion to be drawn from this is that a safety aim that only attempts to progressively reduce the probability of occurrence of "infrequent events" is insufficient. What is needed additionally is the restriction of the amount of damage to an acceptable, no longer catastrophic level. This has to determine our entire course of action. Only when we demand that the dark area representing catastrophic damage in the risk spectrum should also be avoided will our safety aims be comprehensive enough.

After Bhopal Union Carbide equipped several plants with a computer-controlled safety system connected to a meteorological station. Based on the dispersion values of any escaped chemical and the weather conditions it aimed at the rapid calculation of the direction and speed of a toxic cloud. Thus, at least in theory, makes it possible for a catastrophe alarm warning to be given in good time and for adjoining housing to be evacuated. This is undoubtedly one way of restricting the damage inherent in any given risk. Active safety systems such as this, however, require an extremely high standard of quality and high redundancy levels, but even then they are still not safe from "computer bugs".

Both active and other additional, i.e. passive safety systems are aiming at a technology that can fail without catastrophic damage. Only a technology safe within such limits is acceptable in the long term.

4. CONCRETE COMPONENTS AS PASSIVE SAFETY SYSTEMS

The aim in a safety context of this kind is the introduction of a passive safety system which, independent of the probability of accident consequences, rigorously restricts the volume of damage caused by such events. This can be achieved by structural safety measures using concrete components. What makes this passive safety systems so valuable is their almost deterministic reliability when compared to active safety systems. They are independent of accidents caused by human error, which for 80 % of all accidents is given either as the only cause or together with technical failure. A typical example of passive safety is the well-known firewall, which prevents fire from spreading not by starting any process or by automatic control technology, but simply by its sheer presence.

The facilities in Mexico City and Bhopal had nothing of this sort. In Chernobyl too safety relied to a great extent on "active safety" principles.

5. THE AIM OF SAFETY MEASURES: ENSURING ENCLOSURE

In all safety measures the main aim is nothing else but to ensure that hazardous materials are enclosed against external and internal influences over relatively long periods.

6. BURST-PROOF ENCLOSURE SYSTEMS

A small leakage in Mexico City caused a disaster because steel pressure vessels were able to explode like bombs. Explosions of this kind are termed "BLEVEs", which stands for "Boiling Liquid Expanding Vapour Explosion". A BLEVE is a physical explosion of the vessel, which "bursts" and is the centre of a more or less devastating wave of pressure, and - if the contents are flammable - of a wave of heat as well. The result is then a fireball. The waves of pressure and heat together with container fragments acting as missiles may also cause adjacent containers to undergo a BLEVE. Any facility can be completely destroyed by such a "domino effect", as happened in Mexico City.

Similar events can and will happen again elsewhere, because only very few containers today are likely to be sufficiently safe against BLEVEs.

What are needed are pressure vessels with a structure that is not only unaffected by BLEVEs but is also as far as humanly possible BLEVE-proof.

These containers are now available and can be built. Made of reinforced and prestressed concrete of varying shapes, they form an entire family of containers: for cryogenic and non-cryogenic liquid gases, and for flammable or toxic liquids [1].

All containers in this family are:

- safe against the effects of catastrophes, as far as humanly possible

and

- technically and economically efficient.

When operating pressures are high the container is in the shape of a spherical shell (Figure 2). The dimensions in Figure 2c relate to pressure liquefied propane. Figure 2d represents the construction process in which the sphere, consisting of several parts, is expanded and thus prestressed, then being closed to form a monolithic shell.

In contrast to Mexico City the containers in Bhopal are all very small and cylindrical. A concrete enclosing shell in Bhopal could also be cylindrical in shape. The ideal solution would be to combine them into larger units again spherical in shape.

Concrete pressure vessels, owing to their structure, have high redundancy levels. They cannot burst and are resistant to perforation and fire, e.g. [1]. In steel pressure vessels, on the other hand, the safety elements form a tandem connection, which is why once failure begins the process cannot be stopped. This was proved - not for the first time - by Mexico City.

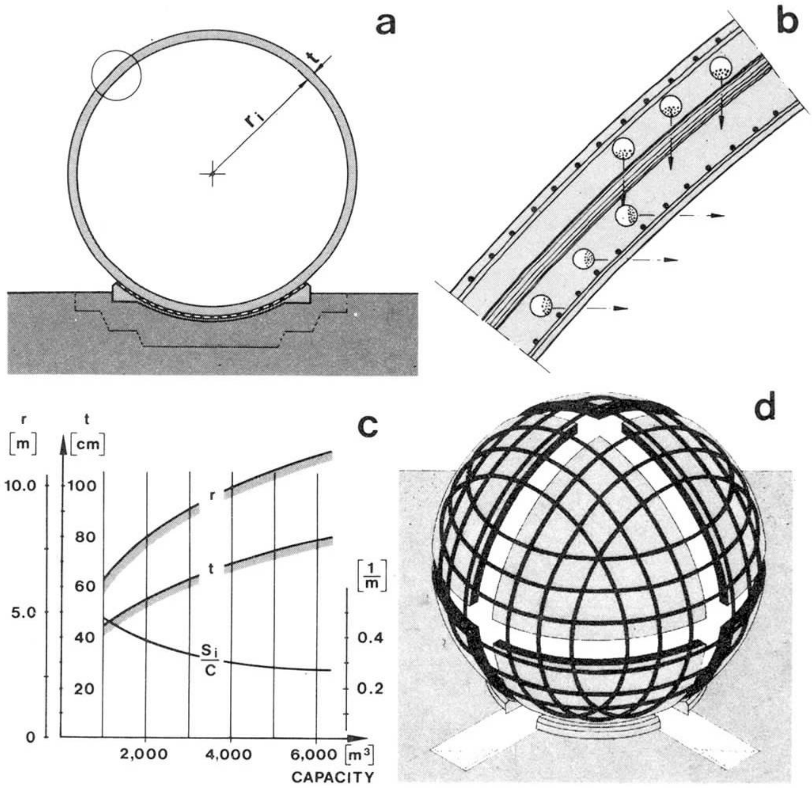

Fig. 2. Spherical concrete pressure vessel

Safety is expensive and more safety is even more expensive. We are used to this and are ready to accept it. The spherical concrete vessel - to restrict ourselves to this shape - should therefore cost more than one made of steel. In fact the reverse is true (Figure 3). The concrete container will cost less. This applies to the entire range of different capacities. Figure 3 shows the results of a cost comparison based on the pressure storage of liquid propane - in other words, one suitable for Mexico City. In such a case concrete containers can cost up to 40 % less than steel containers designed on the basis of the ASME Code. So we have good reason to assume that the new quality of safety we are discussing here and the higher availability connected with it will cost considerably less than what is still being built world-wide today.

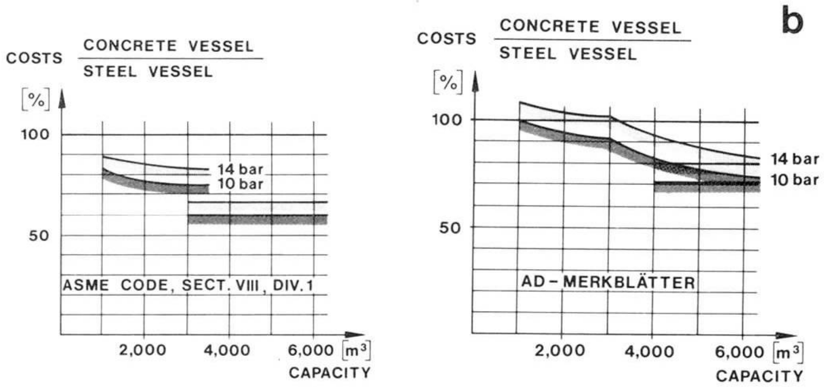

Fig. 3. Costs ratio of spherical pressure vessels

The full economic advantage will and can display itself only if an entire facility, including all smaller safety distances and all other safety elements, is designed on the basis of concrete containers.

7. "MATERIAL TECHNOLOGY" AND "SYSTEM TECHNOLOGY" IN THEIR SIGNIFICANCE FOR ENCLOSURE SYSTEMS

So far we have discussed the enclosure of environmentally hazardous raw materials and products. However, waste materials are also involved in the material cycle. They too require to be reliably enclosed, frequently over very long periods of time, unless they can be recycled or their eluates are not harmful.

While the composition of raw materials and products - and thus how they will affect the enclosing system - are known, this does not as a rule apply to waste materials. If this is so, then material technology will lose its dominating role in the design of reliable enclosure systems, because we do not know which enclosing material - or whether there is one at all - can resist the effects of the waste material. System technology must now take the place of the material technology as the dominant technology. Only with its help will we be able to counter at the earliest stage any material-induced failure in the enclosing system.

8. SAFETY AIMS AND SAFETY MEASURES FOR MATERIALS WHICH ATTACK THE ENCLOSING SYSTEM IN A NON-DIFFERENTIABLE MANNER

The concept of risk is no longer applicable to material systems that can destroy the system enclosing them, so to speak as a result of their inherent nature. In such cases the risk of failure can no longer be limited. The safety aims detailed in Section 3 above must therefore be extended accordingly. From a structural point of view this means that the enclosing system can be guaranteed safe only if, and only then, it is designed in all its parts to be accessible to checks, to be repairable in a way that is accessible to checks - repeatedly repaired if necessary - and to be renewed. This is a new, entirely unusual design aim.

From this point of view enclosing systems for waste materials must differ markedly from those designed for raw materials and products, with regard to attention paid to safety and thus also to construction. Existing sytems do so - unfortunately in the reverse direction. Many waste storage dumps existing today are preprogrammed to becoming future liabilities, because the reliability of the enclosing systems continues to be - and is continually - wrongly assessed.

Waste material storage facilities for substances representing an environmental risk must be in the form of buildings - there is no way of avoiding this if we are serious about environmental protection.

9. ENCLOSING SYSTEMS THAT CAN BE CHECKED, REPAIRED AND RENEWED

We will describe a number of solutions to problems involving the storage of waste materials, these being based consistently on the safety aim of an enclosing system that can be checked, repaired and renewed [2]. This enclosing system has, as we shall see, a modular construction. This means that all solutions are adaptable, adaptable to very different requirements depending on whether - and how - the waste substances have been pre-treated.

All shapes are possible for the enclosing system, examples being mound-shaped dumps (Figure 4a) and container dumps (Figure 4b).

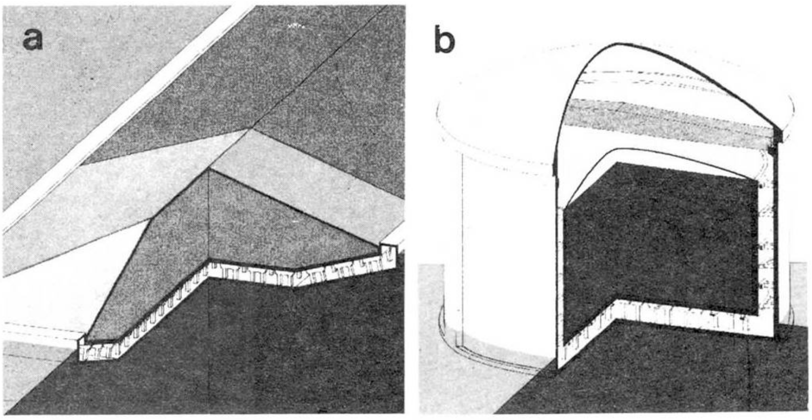

Fig. 4. Controllable, repairable and renewable enclosure systems for wastes

In the detailed cross-section of a container dump here considered as an example the modular construction can be easily recognized (Figure 5a). The elements from inside to outside are: Plate filter, plate lining, inside wall parts with supports to outside wall. As far as possible filter and lining material will be adapted to suit the task in question - in this example we dealing with the storage of untreated waste. Inside and outside walls are made of concrete.

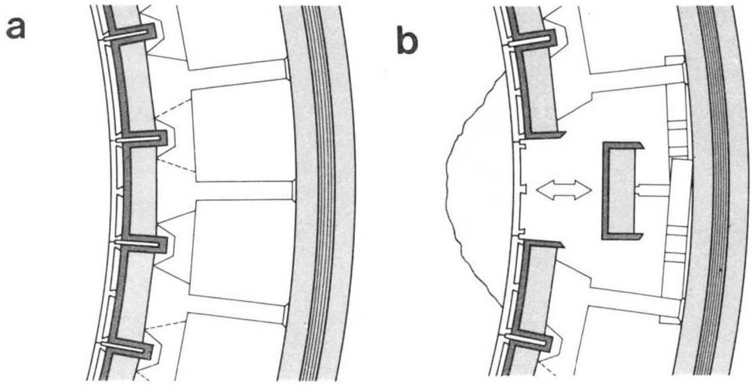

Fig. 5. Container-dump. Details of cross-section

How is repair work to be performed? How are parts to be replaced? This is also shown in the cross-section details given in Figure 5b for the container dump. The working operation is roughly as follows: Compact the waste locally, with the container remaining filled. Separate the lining seams, move the enclosing element hydraulically into the annular space - into the working position - repair and renew defective elements, e.g. plate filters, plate linings or even the concrete of the enclosing elements, return the element into its normal position, weld the seams of the lining together again - and the entire operation is completed. In the base area of the enclosing system work is performed in a similar manner. The same applies to the mound-shaped-dump.

This enclosing system is quite consciously based primarily on the principle of passive safety.

The design of the system allows for errors. The system is quite intentionally designed to accommodate a phase of trial and error. This means that technical and human errors can be kept under control and corrected.

The design however also contains redundancy elements, with all parts of the system being completely accessible. All working operations - the carrying out of checks, repairs, renewal work, including functionality tests, can be repeated as often as required.

Reliability in waste storage enclosing systems does cost more (Figure 6). Since the construction of earth waste dumps with a combined sealing enclosure and temporary roofing is still relatively frequently considered as a solution to the waste dump problem, let us use a dump of this kind as a comparison. The mineral sealing course should have a thickness of 1.5 m and the plastic lining course should be 3 mm thick. For non-pretreated waste - in this case the dump is then a biological and chemical reactor - the container dump costs 2 to 3.5 times as much as for this simple earth dump - for dumps with small capacities twice as much, for those with larger capacities 3.5 times. If the waste has been mineralized costs for the container dump will be halved, those 2 to 3.5 times being reduced to 1 to 1.7 times. Markedly cheaper than the container waste dump is the mound-shaped dump.

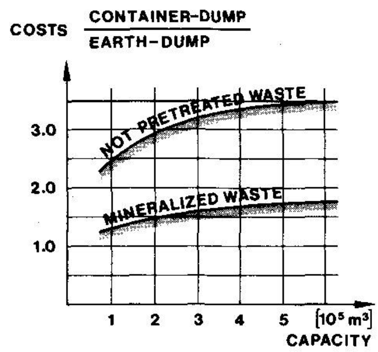

Fig. 6. Costs ratio of waste dumps

These comparisons show that expenditure on reliability does not increase exponentially as is sometimes assumed, but what does rise exponentially is the limitation of damage to the environment. Earth waste dumps with combined sealing enclosures permit neither checks nor repairs, and, since the effects caused by wastes are for the most part non-differentiable, they are with great probability condemned sooner or later to their own "ruin" from within themselves, and to the failure of the enclosing system. Claiming that reliable leakage rates for such a failure can be defined is an illusion.

10. CLOSING REMARKS

Today's trial and error procedures are no longer appropriate when environmental catastrophes caused by technology are concerned. The danger potential is too great for this, and a detrimental interaction of materials and factors which increase uncontrollably through their effect on each other is too probable. We can no longer live with this situation, and we do not have to. This report attempts to show this.

The task facing us all is to bring concrete structures as a preventive answer to environmental catastrophes into the public discussion of safety - a discussion that up to now has not been given a direction and which is stumbling from one disaster to the next. Used in the right way technology can and also must serve to protect the environment, and thus to conserve the quality of life. The better this principle is understood and put into practice, the less society will be tempted to reject technology.

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