Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 8 (1968)

Artikel: Optimisation of structures

Autor: Vasco Costa, Fernando

DOI: https://doi.org/10.5169/seals-8749

Optimisation of Structures

Optimisation des structures

Optimierung von Tragwerken

FERNANDO VASCO COSTA
Prof. Technical University
Lisbon

In Prof. J. Courbon's opinion "the optimisation of a structure consists of designing and constructing that structure at the lowest cost, with the object of fulfilling a well defined purpose. In particular the safety factor must be specified. ..."

A more general definition of optimisation is suggested, based not on the lowest cost but on the lowest overall expenses incurred during service life, including the initial cost of the structure. Such definition can be phrased as follows: the optimisation of a structure consists in designing and constructing that structure so as to minimize the sum of the initial cost plus the present value of the maintenance and operating expenses plus the expectation of all expenses incurred in case of accident or obsolescence(1). The safety factor of each structural element has to be selected so as to fulfill such purpose.

The consequences of failure are not the same for all the elements of a given structure: for some of them failure can bring about complete collapse of the structure, whilst for other elements an easy repair will be possible without discontinuing service.

Why not therefore regard the safety factor as one of the parameters that the designer has to choose while respecting certain rules, just as he does with the materials, the type of structure, and the particular method of construction ?

As there is no value of the safety factor that will give a clear cut limit between safe and unsafe design, there is no reason for specifying its value once and for all, as most codes of practices do. The safety factor of each element of

(1) Expectation is meant here as the probability of the accidents multiplied by the amount of the expenses incurred.

a structure has instead to be chosen taking into consideration not only the initial cost but also the maintenance expenses and the possible consequences of accidents.

What has been said of the different elements of a structure does also apply to structures of the same type but used in different circumstances, the failure of some having much more costly consequences than the failure of others. This would be the case of a dam located respectively upstream or downstream a town.

In general a higher safety factor implies an increase in the initial cost of an element or of a structure, but it permits of a reduction of the maintenance expenses and of the risk of accidents. A lower safety factor, on the other hand, permits of a lower initial cost, but implies an increase in maintenance expenses and in the risk of accidents. In general it also permits of an easier and cheaper adaptation to changing service conditions. But no safety factor, even much larger than the ones usually adopted, will ever give absolute safety.

Instead of minimizing the initial cost of a structure by taking a safety factor specified beforehand, one can try to minimize a generalized cost consisting of initial cost plus maintenance expenses plus expectation of expenses to be incurred in case of possible accidents, all such costs being expressed in terms of the safety factor.

This will permit of a very general approach to the problem of the optimisation of a structure by taking into account not only the parameters mentioned in the report but also the safety factor.

As a good example of such optimisation procedure, the most economical height of some dykes that protect the Netherlands against sea invasions has been chosen by finding the elevation H such that

$$\frac{d\left[C(H) + De^{-\alpha(H-H_o)}\right]}{d\,H} = 0$$

where

H – elevation of the top of the dyke

C(H) – cost of the dyke as a function of H

α – a factor depending on the frequency with which certain sea levels are reached

H_o – lowest theoretical elevation of dyke top

D – expenses incurred in case of overtopping of the dyke

Interest rates are currently very high. It seems therefore worthwhile to take into account the time value of money by deferring expenditure as much as possible. This can be done by reducing the initial cost, even when this implies increased maintenance expenses and higher risks during the service life of the structure.

Let us call

C – initial cost

m – number of types of failure envisaged for a given structure.

n – number of periods of time – usually years – of the service life of the structure.

$p_1^i, p_2^i \dots p_j^i \dots p_m^i$ – probability of each type of failure during each period of time i.

$D_1^i, D_2^i \dots D_j^i \dots D_m^i$ – direct expenses with repair costs for each type of failure, and, where applicable, cost of replacing the entire structure.

$I_1^i, I_2^i \dots I_j^i \dots I_m^i$ – indirect expenses incurred for each type of failure, such as indemnities to third parties.

$M_1, M_2 \dots M_i \dots M_n$ – maintenance and operation expenses during each period of the structure's service life.

$P_1, P_2 \dots P_i \dots P_n$ – survivalship of the structure, i.e. the probability of its being maintained in service during each period of time, taking into account all causes for discontinuance of service including accidents and obsolescence.

r – interest rate.

Depending on the type of structure, the probability of failure p, the repair costs D, and the indirect expenses I, will either decrease or increase with time.

The expectation of all expenses involved in all types of failure can be evaluated for each period of time i by

$$E_i = \sum_{j=1}^{m} p_j^i \left(D_j^i + I_j^i\right)$$

The most economical structure will, on the long run, and taking into account the parameters just mentioned, be the one that renders the following sum a minimum:

$C +$	initial cost
$+ (M_1 + E_1)(1 + r)^{-1} +$	present value of all expenses incurred during 1st year
$+ (M_2 + E_2)(1 + r)^{-2} P_1 +$	ditto for 2nd year
$+ (M_3 + E_3)(I + r)^{-3} P_1 P_2 +$	ditto for 3rd year
$+ \dots\dots\dots$	
$+ (M_n + E_n)(I + r)^{-n} P_1 P_2 \dots P_{n-1} \longrightarrow$	min

Depending on the type of structure, maintenance and operation expenses M and the survilvalship of the structure P can either increase or decrease with time. If there is no reason to envisage the discontinuation of service, e.g. because the structure will have to be rebuilt even in case of total collapse, then P_1, $P_2 \ldots P_n$ can be taken as unity in the above expression.

If p, D, I, M and P can be assumed to remain constant, and P taken as unity, the expression can be given the much simpler form

$$C + a_{\overline{n|}} (M + E) \longrightarrow \min$$

where $a_{\overline{n|}}$ is the "series present value factor", given by

$$a_{\overline{n|}} = (1 + r)^{-1} + (1 + r)^{-2} + \ldots \ \ldots + (1 + r)^{-n}$$

Although the values to be introduced in the above expressions are difficult to evaluate, particularly the expectations, these expressions or a similar ones could permit of a quantitative evaluation of the safety factor leading to the most economical structure, on the long run. It will also enable the influence of the usable life of the structure to be considered quantitatively in design, the same applying to its maintenance and operation costs and to the possibility of its adaptation to foresseable changes, as reccommended by the reporter in the opening paragraph.

SUMMARY

A more general definition than the one given at the beginning of the report is suggested, based not on the lowest cost of the structure for a specified safety factor, but on the lowest overall expenses incurred during the service life, namely initial cost, maintenance, operation and risks of both accidents and obsolescence. The safety factors of each structural element and of the whole structure have to be selected so as to fulfill such purpose.

Such definition can be phrased as follows: the optimisation of a structure consists in designing and constructing that structure so as to minimize the sum of the initial cost plus the present value of the maintenance and operating expenses plus the expectation of all expenses incurred in case of accident or obsolescence.

RÉSUMÉ

On propose pour l'optimisation d'une structure une définition plus générale que celle présentée au début du rapport, ayant pour object non pas la structure au moindre prix pour un coefficient de sécurité imposé, mais la structure la plus économique en service, compte tenu de tous les frais de service y compris ceux

d'entretien, et des risques d'accidents et d'obsolescence. Les coefficients de sécurité pour chaque élément et aussi pour l'ensemble de la structure, doivent être choisis conformément à cet object.

A cette définition on peut donner la forme suivante: l'optimisation d'une structure consiste à concevoir et à realizer la structure de façon à rendre minimum la somme de son prix avec la valeur actuelle des frais d'entretien et avec l'éspérance mathématique des frais directs et indirects que puisse entraîner des accidents ou des modifications prévisibles des conditions de service.

ZUSAMMENFASSUNG

Es wird eine erweiterte Definition des Begriffs "Optimierung eines Tragwerkes" vorgeschlagen, worin neben den Erstellungskosten auch die zu einem späteren Zeitpunkt noch zu erwartenden Kosten (Unterhalt und Risiken) mitberücksichtigt werden sollen. Dies wäre die wirtschaftlichste Lösung auf weite Sicht.

Eine solche Definition könnte folgendermassen lauten: Die "Optimierung eines Tragwerkes" besteht aus der Wahl des zweckmässigen Sicherheitskoeffizienten jedes Tragwerkes und aus der wirtschaftlichsten Verbindung zwischen Projekt - und Erstellungskosten mit den laufenden Unterhalts - und Bedienungskosten und den auf statistischer Vorhersage zu erwartenden Kosten gelegentlicher Unfälle und eventueller Aenderungen.

Leere Seite
Blank page
Page vide