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Design Model for Damaged Concrete Pipes in the Ground

Modèle de calcul de buses détériorées dans le sol

Rechenmodell für Betonrohre im Boden

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SUMMARY

Chemical attack on concrete pipes decreases the thickness of the walls unequally, which influences the internal distribution of the forces. To determine the remaining load bearing capacity of the pipes, a design model has been developed. Deflection has been chosen as the new assessment criterion. The permissible deflection depends on serviceability requirements, mainly leakage. With reference to this criterion the loads on the pipe and the strength of the pipe have been determined. A guideline is given to establish the remaining life expectancy.

RÉSUMÉ

Par l'attaque chimique de buses en béton l'épaisseur de la paroi diminue inégalement, ce qui influence des efforts intérieurs. Pour déterminer la résistance à la rupture des buses, un modèle de calcul a été développé. Comme critère de comparaison on a choisi la flexion. La flexion admissible dépend des exigenges d'emploi: principalement le coulage. Sur la base de ce critère, les sollicitations sont déterminées et la résistance des buses est contrôlée. Des directives sont données pour déterminer la durée de vie des buses détériorées.

ZUSAMMENFASSUNG

Chemische Beeinträchtigung von Betonrohren im Boden vermindert die Wanddicke ungleichmässig, womit die innere Kräfteverteilung beeinflusst wird. Um das Tragvermögen von beschädigten Rohren festzustellen, ist ein Rechenmodell entwickelt worden. Für das Beurteilungskriterium wurde die Durchbiegung gewählt. Die zulässige Durchbiegung hängt von den Gebrauchsanforderungen ab, hauptsächlich von der Leckage. Mit Bezug auf dieses Kriterium werden die Belastungen auf die Rohre und die Festigkeit des Rohres bestimmt. Zur Ermittlung der Restlebensdauer sind Hinweise gegeben.

INTRODUCTION

The sewerage is an important part of the civil infrastructure: both as function and as replacement value.
Still the maintenance of, and the care for the sewerage have not been in proportion to this great importance.
However by the increasing interest in the field of the environment but also as a result of recently established damage, the interest in technical and economical aspects of the sewerage is growing.
A number of these cases of damage is owing to deterioration of concrete sewer-pipes.
The thickness of the walls of the pipe decreases (depending on the appearing mechanism above or below the waterlevel), resulting in a decrease of the strength and rigidity.
To establish the remaining strength, the existing design methods cannot be used because the pipe is not longer axial symmetrical and besides the design assessment criteria of concrete pipes are not applicable to damaged pipes. In many cases e.g. the pipes are already cracked.
Therefore the Delft University of Technology has, in coöperation with D.H.V. Consulting Engineers Amersfoort, developed a design model for damaged pipes in the ground to establish the remaining strength, whereby another assessment criterion has been applied [1].

DETERIORATION

Biogenic Sulphuric acid Attack (BSA) of concrete is the dominant material degradation process in sewers [2]. Because sulphuric reacts with the cement, concrete looses cohesion, resulting in a decrease of the thickness of the pipe wall. This deterioration takes place - as opposed to other mechanism - above the water-level and is not uniformly distributed along the inside of the pipe. As approximate guide values for the deterioration at the top and the water-level are given 1,5 times respectively 2,5 times the mean value [3]. See figure 1.

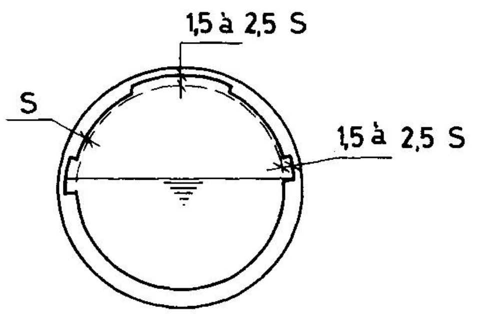


Fig. 1 Schematization of the deterio ration of the pipe-wall

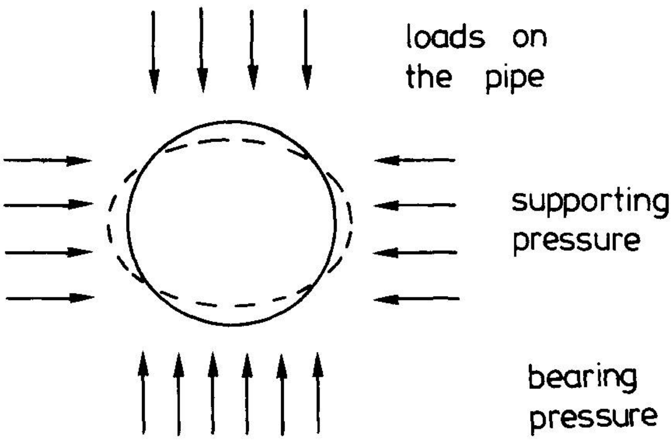


Fig. 2 Behaviour of a relatively flexible pipe

The decrease of the thickness of the pipe-wall has two effects: the pipe is getting less rigid and less strong.
By the first effect the pipe deforms, the surcharge decreases and the horizontal supporting pressure increases. Generally speaking a decrease of the rigidity causes a more favourable distribution of the loads (figure 2). By the second effect the loadbearing capacity decreases.

LOADS ON THE PIPE

The loads on the pipe are determined with the method of Leonhardt as described in [4]. Considered are:

- earth load;
- live load;
- selfweight op pipe;
- pipe filling;
- internal and external pressure;
- temperature differences.

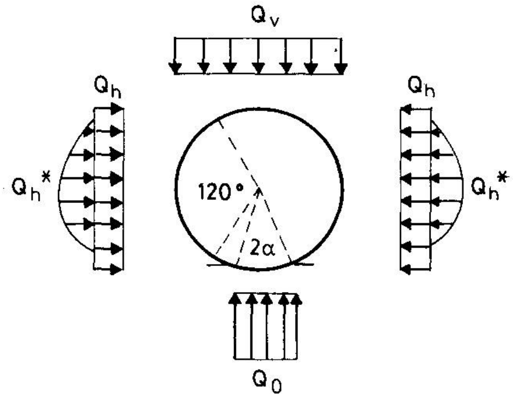


Fig. 3 Schematization of the external loadings in the pipe

The schematization of the external loads is given in figure 3, where:

Q_h = vertical load
Q_h^* = horizontal supporting pressure, as a result of the deformation of the pipe
2α = bearing angle

To determine the earthload, the system stiffness λ (the ratio between stiffness of the pipe and the ground around the pipe) is very important. With a relative low value of λ, Q_v will increase by the deformation of the pipe.

INTERNAL DISTRIBUTION OF THE LOADS

As the study is confined to the circumferential analyses of concrete pipes, longitudinal bending moments are not included. This is deemed to be a permissable simplification where the properties of the trench bottom are uniformly distributed.

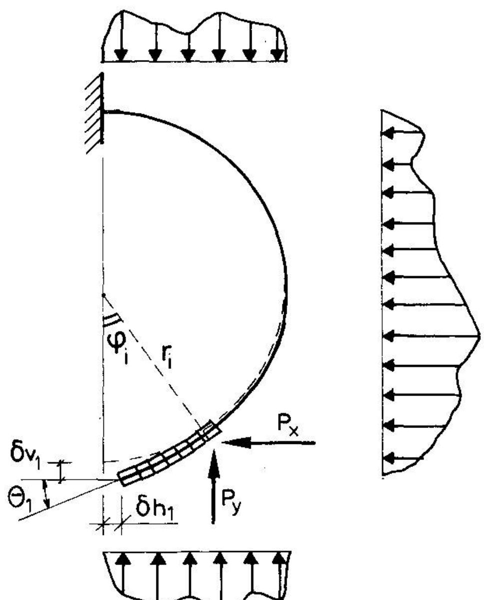


Fig. 4 Arc of circle restrained

The flexural stiffness of the pipe-wall varies along the circumference, which effects the internal distribution of the loads.
With the help of a computer the problem can easily be solved. Half a circle is devided in a number of segments of which the loads and the flexural stiffness are determined.
The pipe is assumed to be restrained at one side (figure 4). As a result of the loads exists a horizontal displacement δ_h, a vertical displacement δ_v, and an angular rotation ϕ_1.
For reasons of symmetry, ϕ_1 as well as δ_h, is equal to zero. In the bottom of the pipe a normal force N_1 and a moment M_1 acts.

N_1 and M_1 are determined from:

$$\left(\sum_{i=1}^{50} \frac{r_i}{EI_i} \Delta\phi_i\right) M_1 - \left\{\sum_{i=1}^{50} \frac{r_i^2}{EI_i} (1-\cos\phi_i) \Delta\phi_i\right\} N_1 + \Theta_1 = 0$$

$$\left(-\sum_{i=1}^{50} \frac{r_i^2}{EI_i} (1-\cos\phi_i)\Delta\phi_i\right) M_1 + \left\{\sum_{i=1}^{50} \frac{r_i^3}{EI_i} (1-\cos\phi_i)^2 \Delta\phi_i\right\} N_1 + \delta h_1 = 0$$

where:

- r_i = distance from centre to centre of segment i;
- ϕ_i = angle, which together with r_i determines the location of segment i (bottom pipe $\phi = 0$; upper side $\phi = \pi$;
- EI_i = flexural stiffness of segment i.

If N_1 and M_1 are calculated, the normal forces, the shear forces and the moments of all segments can be deterninated.

NEW LIMIT STATE

From practice it is known that pipes are often rejected and replaced on other grounds than structural ones. By leakage i.e. the earth next to the pipe will flow into the pipe with the ground-water. By this the horizontal supporting pressure Q_h disappears and the pipe fails.
To determine the remaining lifetime of the pipe the usual assessment criteria are not suitable. A new criterion in terms of deflection of the pipe, seems obvious.
Deflection is the ratio between the vertical displacement of the pipe and the mean diameter of the pipe and can be expressed as percentage.
The advantage of this criterion is the fact that probably in the near future the connection between crack width and leakage will be found.
In the service limit state deflection, the pipe will be checked on its strength properties (sum of the moments, shear stresses and radial tensile stresses).

DESIGN MODEL

With the assessment criterion deflection both the loads and the internal distribution of the forces can be determined. The pipe may be cracked at maximum four places (the upperside, the bottom and two sides (figure 5)). These cracks are assumed to be hinges. From the point of view of equilibrium a minimum sum of moments has to be resisted in these hinges. The pipe is assumed to collapse if these minimum sum of the moments cannot be resisted or if a fifth hinge exists.
The design model can be divided into two parts:

a. Determination of the loads at the limit state deflection;
b. Checking the strength of the pipes under these loads.

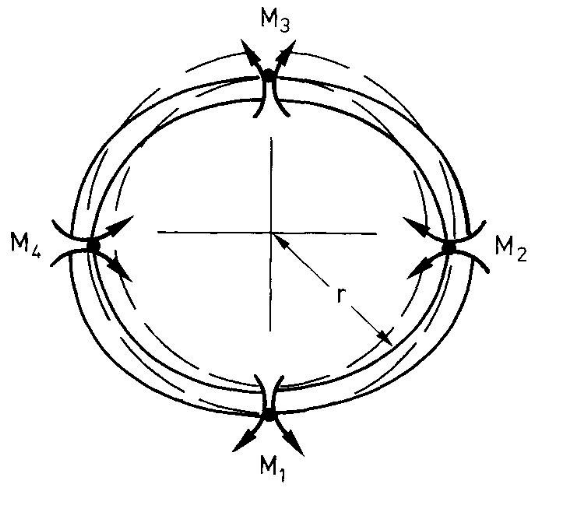


Fig. 5 Sum of the moments in a cracked pipe

re a. Only the earth load, live load and surchange are assumed to be depending on the deflection of the pipe. To determine these loads two different ways are possible:
- to adapt the flexural stiffness of the undamaged pipe till the assumed deflection is found;
- to ascertain the loads directly at a fixed maximum deflection [1].

re b. In the case of reinforced pipes the moment will be resisted by reinforcement, in the case of plain pipes by the eccentricity of the normal force. If the sum of the moments cannot be resisted the pipe is assumed to fail.
Other checks in the model are: the possibility of the development of a fifth hinge and check of the shear forces and radial tensile stresses (see flow diagram figure 6).

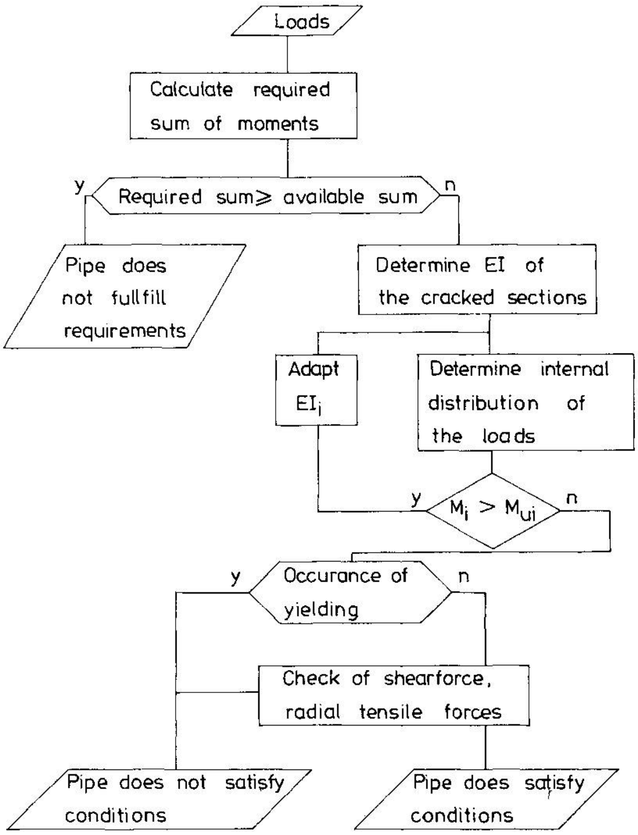
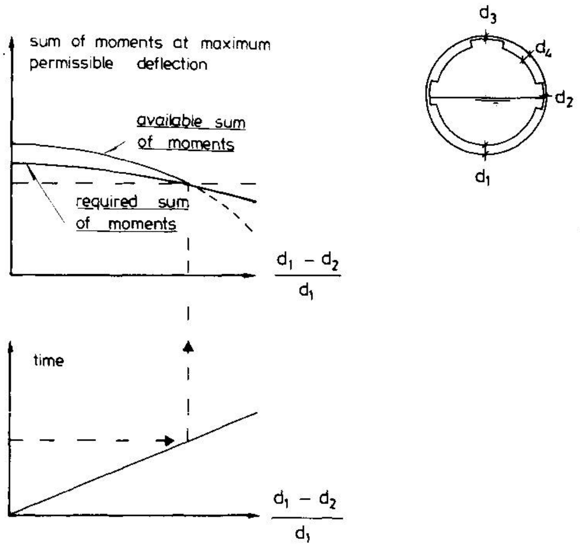


Fig. 6 Flow diagram design model

REMAINING LIFE EXPECTANCY

With the developed design model an indication of the remaining life-time of a concrete sewer pipe can be found; the exactness depends on the data concerning deterioration. Especially knowledge of the speed of the deterioration is important.
Figure 7 shows how this remaining life-time can be determined, assuming that the deterioration is linear in time and only the part above the water-level has been damaged.



d_1 = original wall thickness;
d_2 = wall thickness at water-level;
d_3 = wall thickness at the top;
d_4 = wall thickness between the top and the water-level.

Fig. 7 Example of the determination of the remaining life-time

The speed of the deterioration at the water-level and at the top is two times the speed at the part in between.
The factor $\frac{d_1-d_2}{d_1}$ gives the extend of the deterioration.

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