Shear failure of 30-year-old aqueduct wall?

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Summary

A 3D linear elastic finite element model has been used for the reassessment of the strength of an existing reinforced concrete aqueduct with shear cracks at suspicious locations. With this relatively simple approach very useful results have been obtained. The observed damage appears to be related to local redistribution of stresses, and the overall structural safety seems to be sufficient. However, appropriate measures have to be taken to avoid degradation of the reinforcement. Additionally, the findings should be supported by e.g. refined calculations. This paper describes the finite element model and the results of the linear analysis.

Keywords: aqueduct; reassessment; shear failure; finite element method.

1. Introduction

After the observation of serious inclined cracks in the wall of a 30-year-old aqueduct, the Dutch transportation authority (Rijkswaterstaat) decided to reassess the strength of the structure. In order to judge the vulnerability to shear failure in a controlled way, a phased approach was followed. In the first phase, a linear analysis of the structure had to be carried out, including code checking. The other foreseen phases will consist of an inspection of the structure and refined nonlinear calculations.

After a description of the structure, this paper describes the modelling approach, presents and evaluates the results of the analysis and gives recommendations for the next research phases.

2. Modelling philosophy

In order to assess the structural behaviour as realistic as possible, the client asked a 3D calculation with solid elements. The typical 3D stress results had to be translated in engineering values like normal forces, shear forces and bending moments to enable code checking. Typical shell results (distributed forces and moments) were obtained by using 'composed shell elements' in the DIANA model. Results valid for beam calculations were obtained by integrating the shell results in every section of the shells (Figure 1).

Due to the presence of a dilatation joint at the centre of the aqueduct only half the structure was modelled. Special attention was paid to element size and aspect ratio, in order to obtain a sufficiently fine element mesh to yield accurate and reliable results at relatively low calculation cost.

In reality the aqueduct is founded on underwater concrete and driven piles. The foundation stiffness has been translated into an elastic support of the tunnel walls. The analysis results proved to be sensible for variations in the foundation stiffness. In the calculations a realistic range for the stiffness was taken into account.

Both global and local strength checks have been carried out.

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3. Analysis results

Whereas the global strength and safety appear to be sufficient, at several locations exceedances of the available strength have been found. A stiff central support resulted in bending cracks near that support, although if the central support has lower stiffness shear cracks were predicted near the end supports. This agrees with the observations in reality: an almost vertical crack near the supporting central wall and inclined cracks near the side walls. This indicates load redistribution due to both settlements of the mid support and local stiffness reduction (cracking).

From the original reinforcement drawings it becomes clear that the heavy tension tie reinforcement has no optimal position. The tension tie is positioned in the upper meter of the wall, whereas the largest tension forces act 1-2 m lower. The forces have to be transferred to the tension tie, at the cost of relatively wide cracks. The overall safety however is sufficient, as long as degradation of the reinforcement can be avoided with appropriate measures and frequent inspections.

4. Next steps

After this linear analysis inspections have to be carried out, to be followed by refined calculations. The inspections should focus on cracks, degradation and deformation, in order to be able to validate the findings of the linear analysis and to design appropriate repair measures. The refined calculations should be carried out using realistic (nonlinear) material parameters (cracking, crushing and yielding) and a realistic modelling of the foundation stiffness. The results of both inspection and refined calculation will give a more reliable answer to the question of the probability of shear failure.

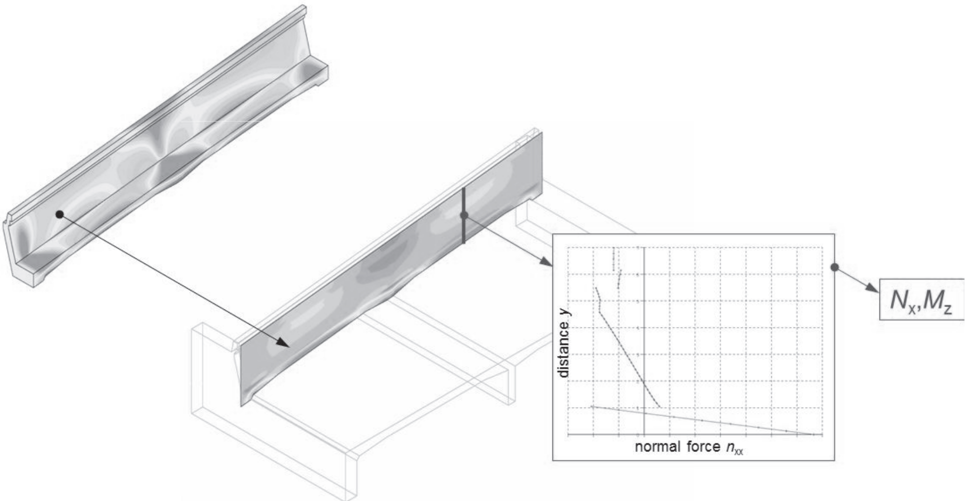

Figure 1: Transformation of 3D stresses of the edge beam to shell forces, and subsequent integration of shell results to beam forces.