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Over-Crossing Concrete Tunnels in Arlandabanan

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Summary

The structural analysis of over-crossing concrete tunnels in Arlandabannan, which is a new high-speed-train connection between the center of Stockholm and the Arlanda airport, is overviewed. The tunnels are of cut-and-cover type and consist of a single-track tunnel crossing obliquely over a double-track tunnel at about 20 - 30 m under the ground surface. The present paper describes a shell structure adopted for the tunnels and summarizes finite element analyses that have been carried through for the tunnels under various loading conditions. Numerical results are presented and suggestions to the structural analysis and design of similar concrete tunnels are given.

1. Introduction

Arlandabanan is a new high-speed-train railway connecting the center of Stockholm and the Arlanda airport. Near the Arlanda airport a railway of about 5,100 m long is constructed under the ground through rock and concrete tunnels. The concrete tunnels are of cut-and-cover type and consist of several different sections, see Mörnstad [1]. In a section near Märstaån a single-track tunnel (Shuttle Tunnel) crosses obliquely over a double-track tunnel (Intercity Tunnel) at about 20 - 30 m under the ground surface, see Fig. 1. The over-crossing part of the concrete tunnels, which is heavily grayed in the figure, is designed as an independent monolith connecting through dilation joints with neighboring concrete tunnels. In the following presentation this monolith will be referred to as *an over-crossing tunnel monolith*. The present paper describes a shell structure adopted for the over-crossing tunnel monolith. The concrete tunnels are subjected to various design loads which are mainly according to the Swedish design codes for building structures [2], also partly according to those for bridge structures [3], railway-bridge structures [4] and tunnel structures [5]. (See also Mörnstad [1] and references therein for the more general design specifications and requirements.) The main part of the paper is to report finite element analyses that have been carried through for this over-crossing tunnel monolith under various design loads, e.g.

underground water, overburden pressure, earth pressure, temperature changes, traffic loads and so on.

2. Thick-Shell Structure

In this over-crossing tunnel monolith the Intercity Tunnel is 97.5 m long and the Shuttle Tunnel 83.2 m. The crossing angle is about 16°. The internal dimension of the Intercity Tunnel is 11.5×7.5 m^2 and that of the Shuttle Tunnel 7.0×7.3 m^2. The thickness of different plates and other geometric parameters are given in Fig. 1. We note that the covering soils over this tunnel monolith differs about 10 m in depth from the southern end (towards Stockholm) to the northern end, see also Fig. 1. Such a 3-dimensional structure with non-uniform loading should be adequate to be modeled as a shell. In the modeling, considering the concrete plates are relatively thick, a thick-shell theory is applied so as to account for the shear deformation through the shell-thickness dimension.

3. Geomechanical Conditions

The bottom plates of both Intercity and Shuttle Tunnels in this tunnel monolith lie on compacted rockfills which are produced through in situ rock-blasting and are considered as an elastic foundation. The thickness of the rockfills is about 0.3 m and its elasticity modulus is 50.0 MPa. The rockfills are supported by hard rocks. The averaged underground water level is +20.5 m with the highest high underground water level at +21.5 m and the lowest low underground water level +19.5 m.

4. Design Loads

The design loads are divided into two groups: permanent and variable loads. The permanent loads include the self-weight of structure, ballast, (vertical and horizontal) earth pressure, water pressure. Notice that the water pressure is associated with three underground water levels. This in turn leads to six different cases in the earth pressure loads. In the group of variable loads, the following loads are considered: train loads, overburden pressure, earth pressure due to the overburden pressure (single and/or double sided), temperature changes (see below) and underground water level variations. Notice that the train loads are dynamic and moving.

The over-crossing tunnel monolith is a thick-walled structure with a closed section. In addition, it is relatively long. The effects of temperature changes have been found to be pronounced. The following cases of temperature changes are considered: (*i*) Temperature difference of ±14° between the outer and inner shell-surfaces (4 cases); (*ii*) Temperature increase or decrease of 10° in the plate shared by the Intercity and Shuttle tunnels.

The permanent and variable loads are combined with different coefficients principally according to the design code *BKR 94* [2]. The following combination categories have been considered: ordinary use, long term use, fatigue, damage. For a more detail specification of design loads and load combination we refer to Jovall [6].

4. Finite Element Analysis

A general-purpose finite element program ABAQUS [7] has been used for the structural analysis of this over-crossing tunnel monolith. In the analysis 8 node thick-shell elements are used. A finite element mesh with 1504 elements, 4607 nodes and 27000 unknown variables are used, see Fig. 2 (left). Linear elastostatics is assumed and dynamic amplification factors are employed to account for the dynamic effects of train loads.

The individual load cases are first applied and it has been found that the dominant design loads are the earth pressure and the temperature changes. This has been used as a guide when performing various load combinations. In Fig. 2 (right), the deformed structure is shown for a combined load case where a load combination for damage is considered.

The temperature load is one of the particularly concerned load cases in the analysis. In Fig. 3 the deformed structure under a temperature load and a section force contour map are plotted.

Notice that there exist seven components of section forces, i.e. two moments, a twisting moment, two normal membrane forces, an inplane shear force and two transverse (thickness direction) shear forces. Hence, huge amount numerical results/data must be processed as max-min section force envelopes must be established in order to carry through the design calculations, e.g. reinforcement calculations, see Jovial [6] and Zeng [8] for the detailed treatment.

5. Closure

Structural analysis of an over-crossing concrete tunnel monolith has been overview in the paper. A shell structure adopted and the finite element analyses carried through for the tunnel monolith have been briefly described. The temperature loads are found to be pronounced. This should be emphasized when similar concrete tunnels are studied. The importance of other practical issues, e.g. processing huge numerical results in an effective manner when structural analysis of a complicated structure is performed, should also be realized.

6. References

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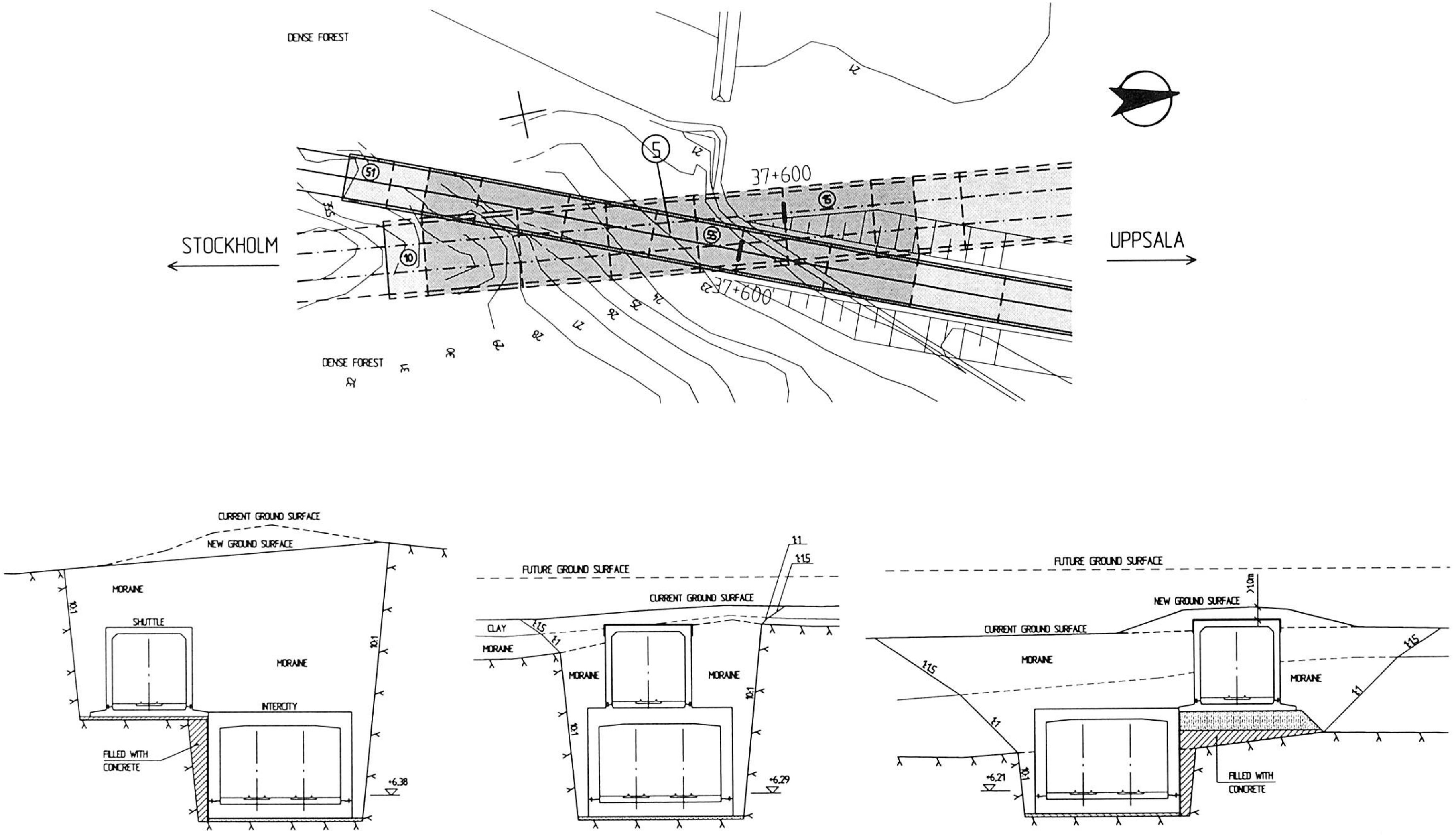

Fig. 1. Over-crossing concrete tunnels at Märstaån in Arlandabanan
- A plan view (upper) and three typical sections (lower).

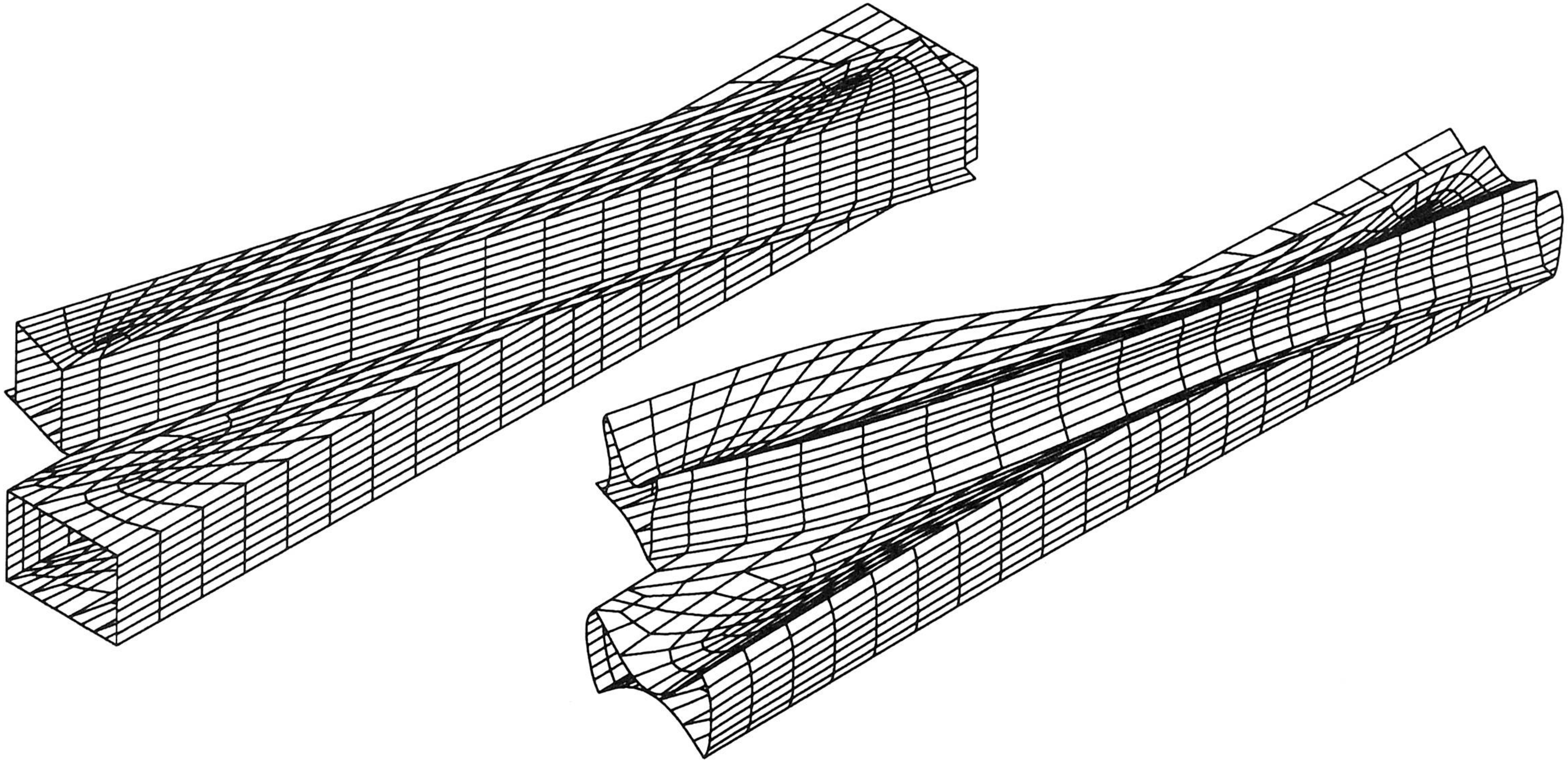

Fig. 2. Finite element mesh with 1504 thick-shell elements (left) and the deformed structure when a combined load case for damage is considered (right)

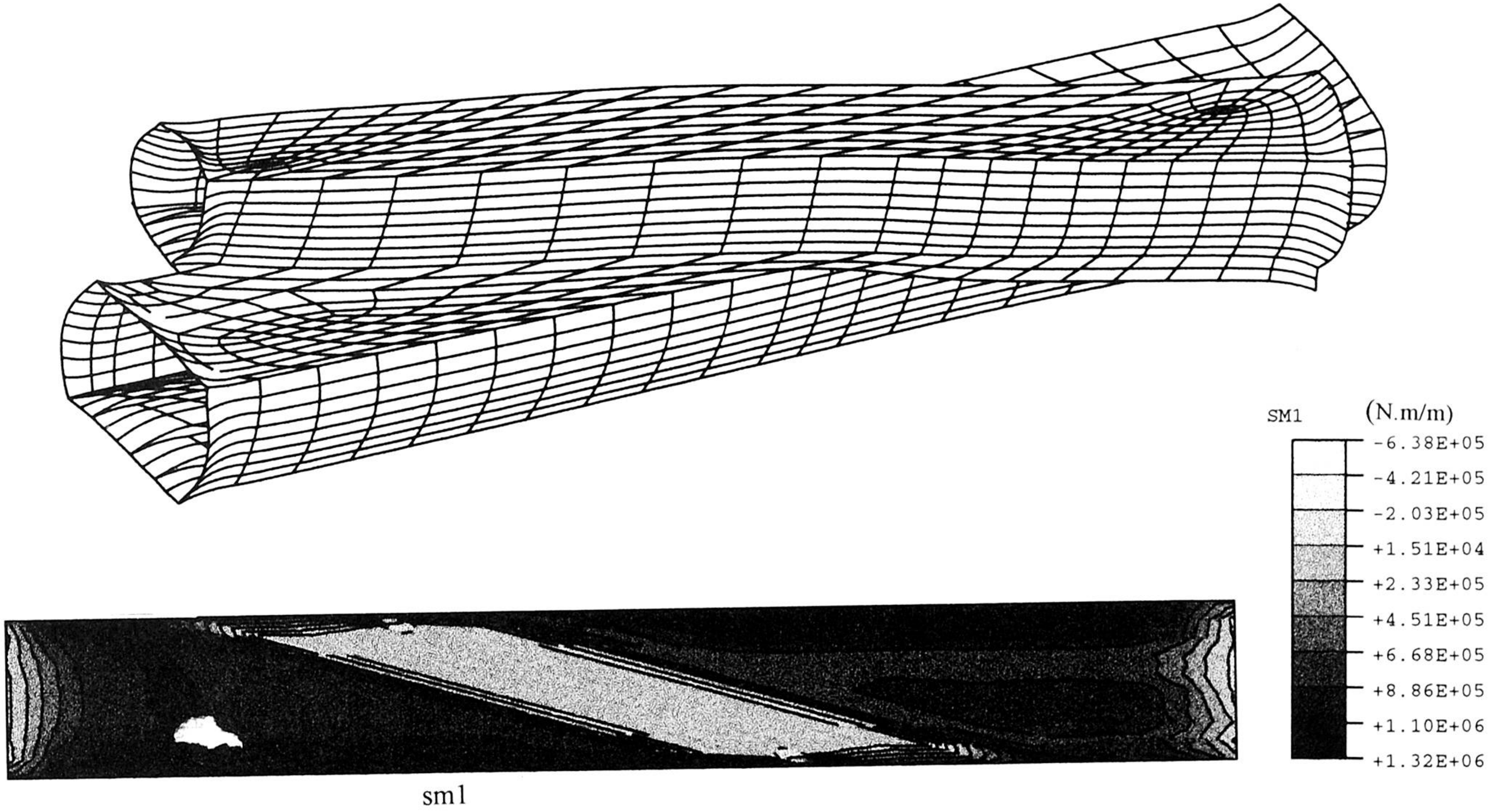

Fig. 3. Deformed structure (upper) and a moment contor map of the Intercity Tunnel roof (lower) when a load of temperature difference of 14° between the inner and outer shell-surface is applied.