EFFECTS OF VARIABLE WIDTH IN THE TWO-DIMENSIONAL SEISMIC ANALYSIS OF UNDERGROUND STRUCTURES

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SUMMARY

This paper describes the stress analysis of a buried tunnel connecting two large buildings in a nuclear power plant and subject to simultaneously horizontal and vertical earthquakes. The analysis is carried out by the superposition method and it focuses mainly on the building-soil-tunnel interaction effects in a vertical section along the tunnel axis, with special consideration of the different widths of the tunnel and adjacent buildings in the third direction perpendicular to the plane of analysis. A comparison of results from the constant-width model and from the variable-width model, reveals small differences in the response spectra, but lower tunnel stresses of up to 20 % in the second case.

INTRODUCTION

For soil structure interaction calculations the plane strain idealisation is considered as a good simulation of the true three dimensional problem (Ref. 1). This approach is based on the use of viscous boundaries and a constant model width in the direction perpendicular to the plane of analysis. The traditional plane strain formulation can be modified in order to account for the different widths of the structures involved.

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METHODOLOGY

The method of analysis used herein consists of a finite element procedure which considers structures embedded in a multi-layered linearly viscoelastic soil system, and a seismic environment consisting of any combination of surface and body waves. This method of analysis is described in detail elsewhere (Refs. 2, 3, 4), and consists essentially of the superposition of the free field motions, u_f, and the interaction motions, u_i, to obtain the total motions, u.

The free field motions are first calculated by solving the site problem for horizontally-layered linearly viscoelastic soils and the desired seismic environment. The interaction motions are calculated from the source problem arising, first, from the difference in mass and stiffness of the soil volume being replaced by the structure and, second, from the specified seismic environment. The source problem is modeled by linearly viscoelastic finite elements.

The input motion was conventionally assumed to be due to simultaneous vertically progagating shear waves and compression waves with maximum horizontal and vertical accelerations of 0.1 and 0.05 g respectively.

FINITE ELEMENT MODELING

Inspection of Fig. (1), indicates that the tunnel behaviour may be significantly affected by the reactor and auxiliary buildings, even through the tunnel is not linked directly to these two structures. Therefore, the significant sections of the tunnel will be as follows:

A. Section A across the tunnel in the Z-Y-plane
B. Section B in the vertical X-Y-plane along the tunnel axis
C. Section C in the horizontal X-Z-plane along the tunnel axis
   Only Sections B and C will be considered herein.

Special consideration is now given to the material properties and stresses of the plane strain model as related to those in the actual system. The actual stresses are calculated by following three steps:

1. "Spread" element properties over the entire width.
2. Solve for plane strain stresses.
3. "Concentrate" plane strain stresses over the actual structure width.

VARIABLE ELEMENT EFFECTIVE WIDTHS

The fundamental assumption in the plane strain model for Section B given in Fig. (2) is that all points along the Z-axis will move in phase, for any seismic input in the X-Y plane. Inspection of the Section C shown in Fig. (1) indicates, however, that under a seismic input along the X-axis, only a part of the soil mass existing between the UJA and ULB buildings will actually move in phase with the corresponding tunnel points. Along any imaginary line parallel to the Z-axis through the tunnel, points situated sufficiently far from the tunnel, will show an out-of-phase response relative to the former. Therefore, a boundary can be defined between both the in-phase and the out-of-phase soil masses. The distance between these boundaries at each side of the tunnel, measured along the Z-axis, are the effective element width for a modified plane strain analysis.

Effective element widths are determined from results of the finite element model shown in Fig. (3). The boundaries between the soil masses which move in-phase and out-of-phase with the tunnel, will be determined by comparing the response spectra in the X-direction, along lines parallel to the Z-axis, as shown in Fig. (4). Although phase differences increase gradually at the different spectral frequencies, it seems adequate to establish that the out-of-phase soil zone begins at points showing spectral differences at frequencies equal to or higher than 1.8 Hz; i. e. the fundamental frequency of the tunnel. The boundaries and the effective widths so determined are shown in Fig. (5).

COMPARISON OF RESULTS AND CONCLUSIONS

A comparison between results from the finite element model in Fig. (2) obtained with constant width and those obtained with variable widths, reveals small differences in the response spectra, and only in the high frequency range. The time-maxima of the tunnel stresses along the tunnel length are compared in Figs. (6) and (7), for both cases of analysis. The obtained diagrams are in both cases similar. The peak values as shown in these Figures indicate differences ranging between 16 % and 20 %.

The decrease in peak stresses results from a relatively higher effect of the viscous boundaries. This stress decrease is relatively small, perhaps due to the fact that the tunnel length is significantly lower than the widths of the adjacent buildings. It is probable, however, that for relatively longer tunnels, the element effective widths will decrease, and consequently, a still larger stress relaxation will occur. Therefore, short of an actual 3-D analysis, the procedure presented herein respresents an improvement in the computation of seismic stresses.

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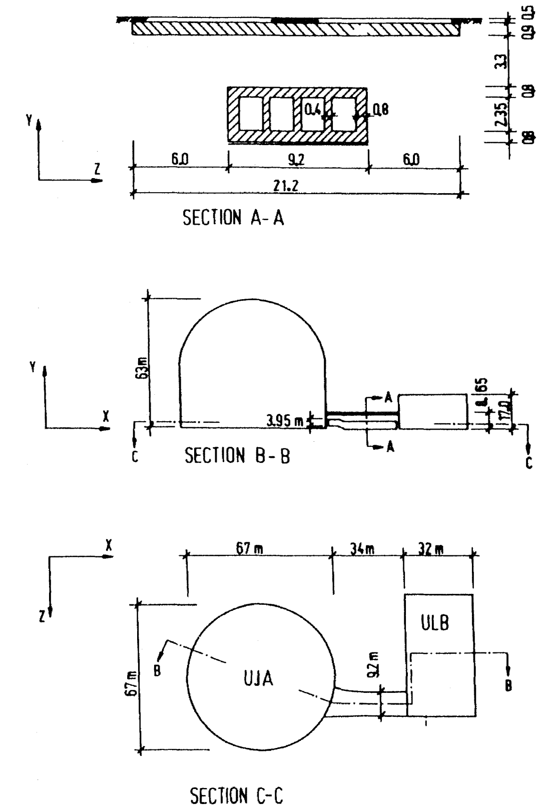

Figure (1): Model Sections for Tunnel Analysis

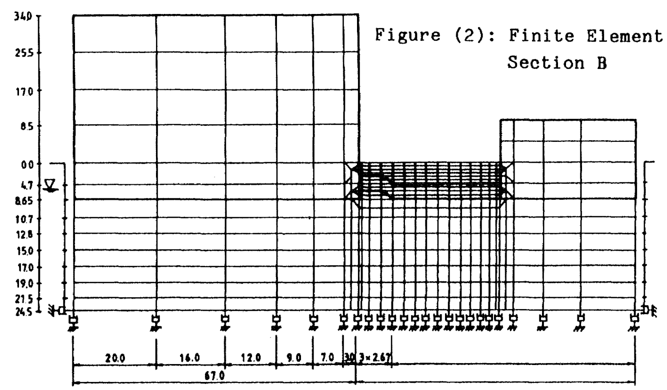

Figure (2): Finite Element Model Section B

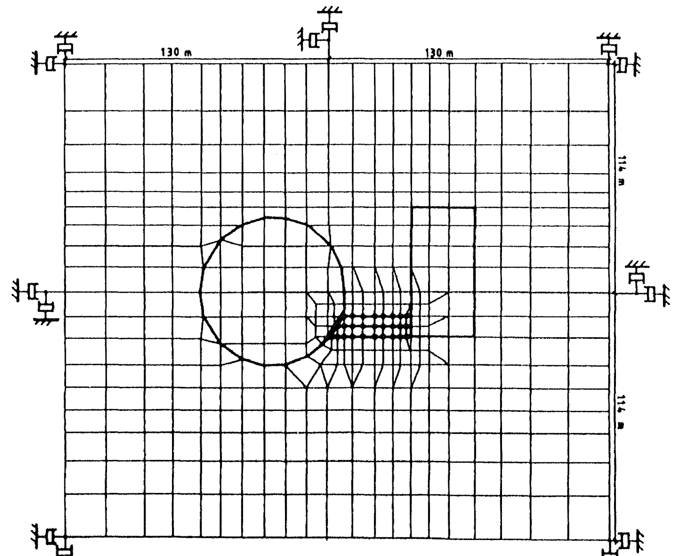

Figure (3): Finite Element Model Section C

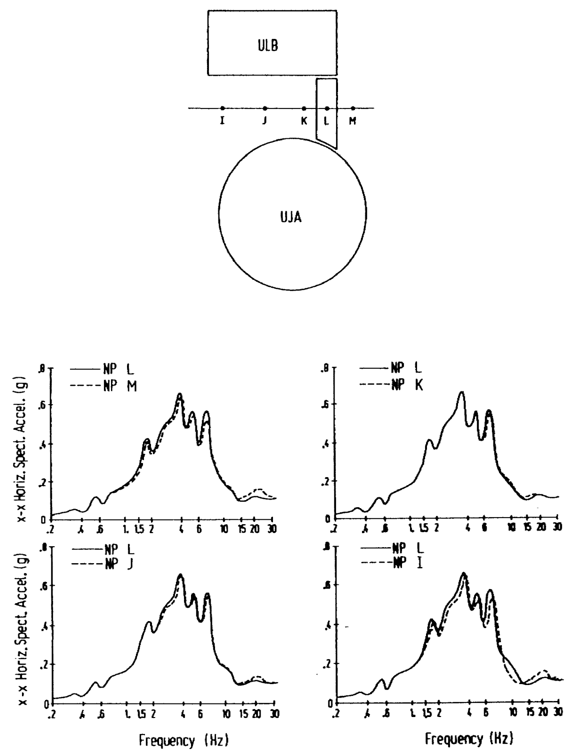

Figure (4): Comparison fo Tunnel and Soil Response Spectra at the Tunnel Midpoint (Section C)

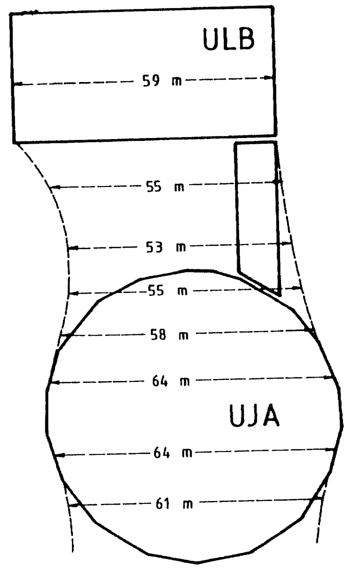

Figure (5): Contour of Soil Mass In-Phase with the Tunnel

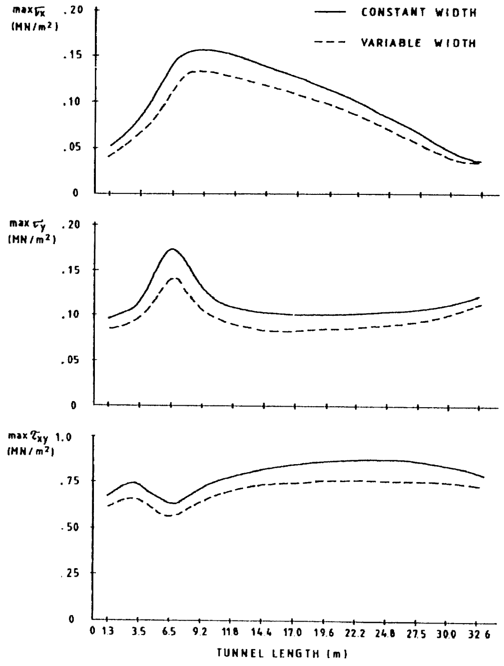

Figure (6): Comparison of Maximum Stresses along the Vertical Tunnel Walls (Section B)

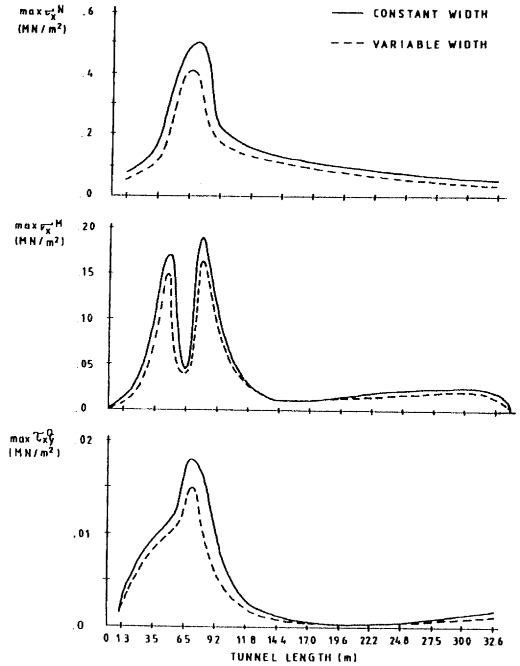

Figure (7): Comparison of Maximum Beam Stresses along Roof and Floor (Section B)