MEMORANDUM

DATE: December 20, 2001

TO: Jim Thomson, P.E., HNTB Corporation

FROM: Michael Bailey, P.E., Reda A. Mikhail, P.E., Hart Crowser, Inc.

RE: **Effect of Shear Modulus on Deformations and Reinforcing Stresses of MSE Walls**
Third Runway Project
4798-40

cc: Mr. John Sankey, P.E., RECo

This memo discusses sensitivity of the wall design to variations in the soil shear modulus. We present a "best estimate" and conservative "worst case" analysis of seismic performance, to serve as a basis for discussion with RECo, on comparison with their observed performance of MSE walls during real earthquakes.

BACKGROUND

The engineering study of the proposed Third Runway includes deformation analyses for the proposed MSE walls under dynamic loading using the finite difference analysis program FLAC. The deformation analysis provides an independent check for the AASHTO-required limit equilibrium, pseudo-static method, because it accounts for critical ground motion and soil stiffness characteristics. One of the critical soil properties that is accounted for in the numerical analysis is the shear modulus. This memorandum summarizes the effect of shear modulus variation on the proposed MSE wall deformations and tensile stresses of the wall reinforcing elements.

Shear modulus of soils is not a constant value, rather it depends on the shear strain level. At a very low shear strain (typically less than 0.001%), the maximum shear modulus is designated as G_{max}. As the shear strain increases due to increasing shear stresses during an earthquake, the shear modulus (designated as G), decreases as illustrated on Figure 1. Curves such as Figure 1 have been published for various soil conditions for use in site-specific seismic response analyses. Initial FLAC analyses for the Third Runway utilized "large

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strain" shear modulus values obtained from on-site pressuremeter tests. The "large strain" shear modulus was considered to represent conditions when large deformations occur due to earthquake shaking and reduce G below G_{max}. During the October 31/November 2, 2001, meeting with the ETRB, brief discussion with the Board indicated that Hart Crowser should assess the effect of variations in the shear modulus.

PARAMETRIC ANALYSIS

Hart Crowser used on-site shear wave velocity measurements as the basis for calculating G_{max}, as recommended in the engineering literature. The site-specific response analyses indicate that G/G_{max} is about 0.55. (We used ProShake for this site response analysis; QUAD4 would likely produce similar results.) Both ProShake and QUAD4 assume elastic soil behavior. This is considered to be realistic for the beginning of shaking, but it is likely unrealistic for larger deformations that occur as shaking continues. On the other hand, the pressuremeter tests performed for the project suggest that for glacial soils, G/G_{max} (large strain) varies from 0.25 to 0.33, which is consistent with the range (0.20 to 0.28) recommended by Bellotti, et al. (1986).

We assumed an average G/G_{max} (large strain) of 0.28 for the fill soils and 0.55 for the very dense glacial till soils below the wall, would most realistically represent conditions at the site. In the FLAC analyses, we used the Mohr-Coulomb constitutive model (elastic-perfectly plastic) for the fill and underlying native soils. The Mohr-Coulomb model assumes a constant value of G for each type of soil. Conceivably, an analysis that considers changes in the shear modulus ratio as strain occurs could be developed, but seems unnecessary, in our opinion. To address the ETRB comment on effect of shear modulus variation in the fill, we compared the results from 0.55 (a relatively unrealistic, "stiff" system representing the beginning of shaking as suggested by the site-specific analysis) and 0.28 (a more realistic "soft" system based on the pressuremeter data, to account for inelastic displacement due to shaking).

MODEL RESULTS

To illustrate the effect of variations in G on the wall deformations and the reinforcing stresses, we performed two FLAC analyses on Section 105+20 (Figure 2) in the North Safety Area (NSA). Two different cases were analyzed, representing the G/G_{max} limits discussed above. The wall deformation results are shown on Figure 3, and the maximum tensile stresses (expressed as a ratio of the yield strength) of the metal strips are presented on Figure 4.

The results suggest that for the stiff conditions that exist at the start of shaking, (G/G_{max}=0.55 for the fill), the lateral deformations and tensile stresses are higher than would occur for the "large strain" case (G/G_{max}=0.28 for the fill). This may be because one effect of displacement due to shaking is to relieve some stress, and that real deformations are less than would be predicted for a very stiff model. Hart Crowser would very much like to hear RECo's opinion on this based on observed wall performance.

The significance of what shear modulus to use, may relate to design changes. As shown on Figure 4, stress in some of the reinforcing elements for the more realistic case (G/G_{max}=0.28 for the fill) exceed the AASHTO allowable stress (0.55 of the yield strength). By comparison, most of the reinforcing elements exceed the allowable stress for the "stiff" case (G/G_{max}=0.55 for the fill) in this analysis. However, it is important to note that even for the "stiff" model, none of the reinforcing exceeds yield strength, and that convergence of the models did not indicate "failure" of the MSE wall.

The FLAC results substantiate the effect of varying the shear modulus on the deformation and reinforcing stresses of the proposed walls, as requested by the ETRB.

We would appreciate comments and input from other members of the design team regarding the appropriate range for G based on case histories, or other modeling.

Reference

Bellotti, R., V. Ghionna, M. Jamiolkowsky, R. Lancellotta, and C. Manfredini 1986. "Deformation characteristics of cohesionless soils in in situ tests," Proceedings, In Situ '86, Geotechnical Special Publication 6, ASCE, New York, pp. 47-73.

Attachments:
Figure 1 - Modulus Reduction Curve
Figure 2 - Section 105+20
Figure 3 - Comparison of Lateral Deformations
Figure 4 - Comparison of Tensile Stresses

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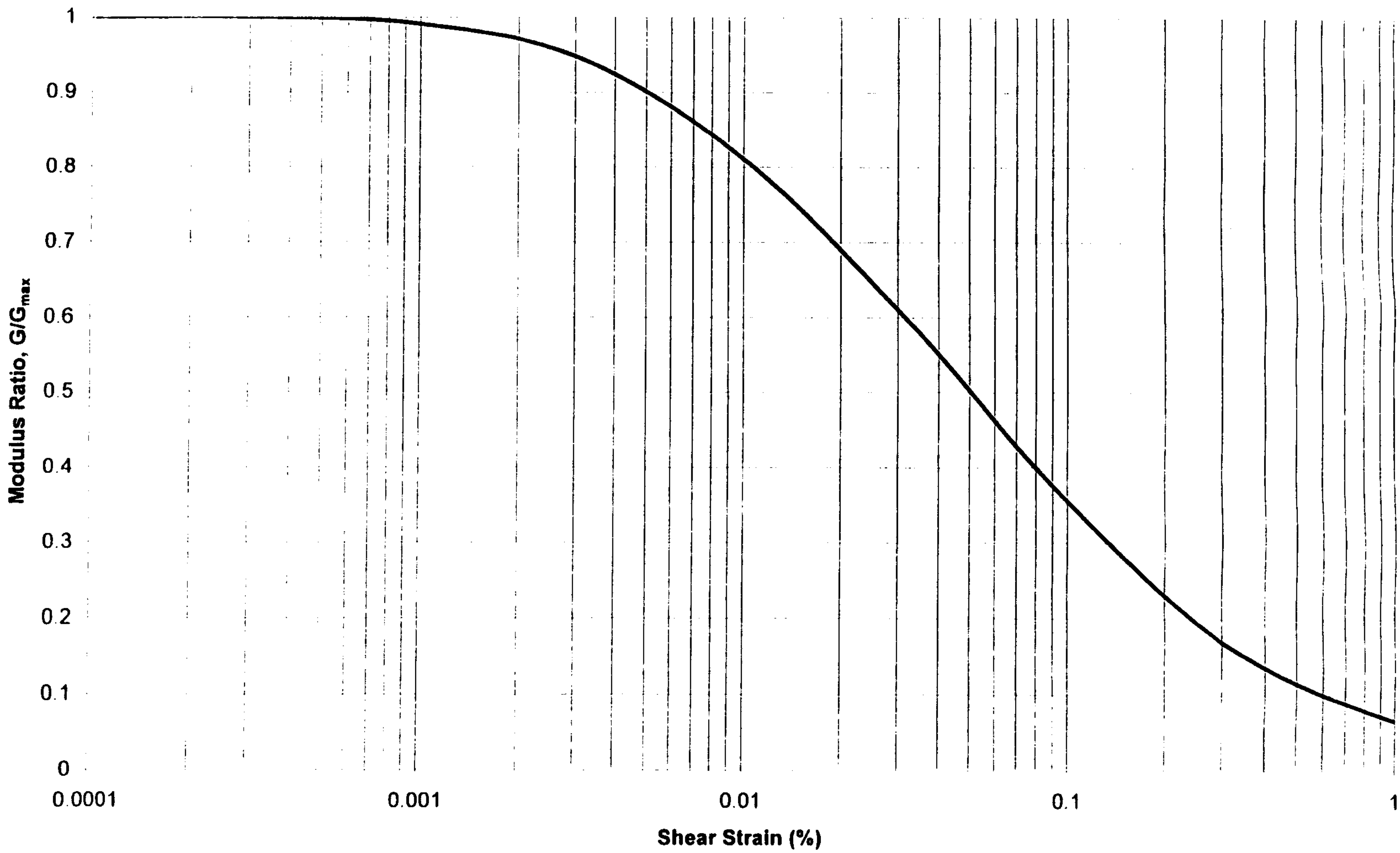
Modulus Reduction Curve



Third Runway
Figure 1

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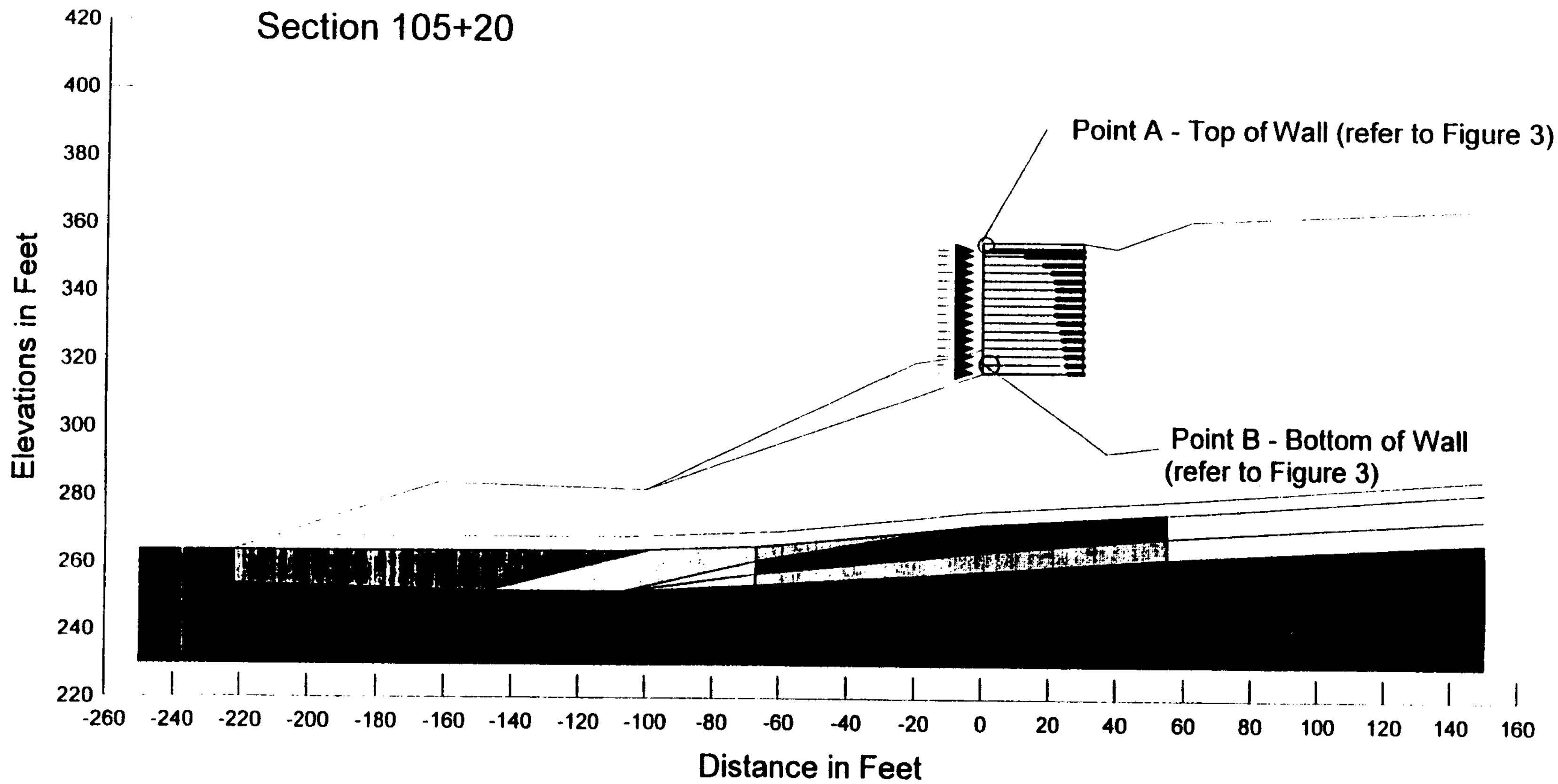

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Figure 2
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Comparison of Lateral Deformations

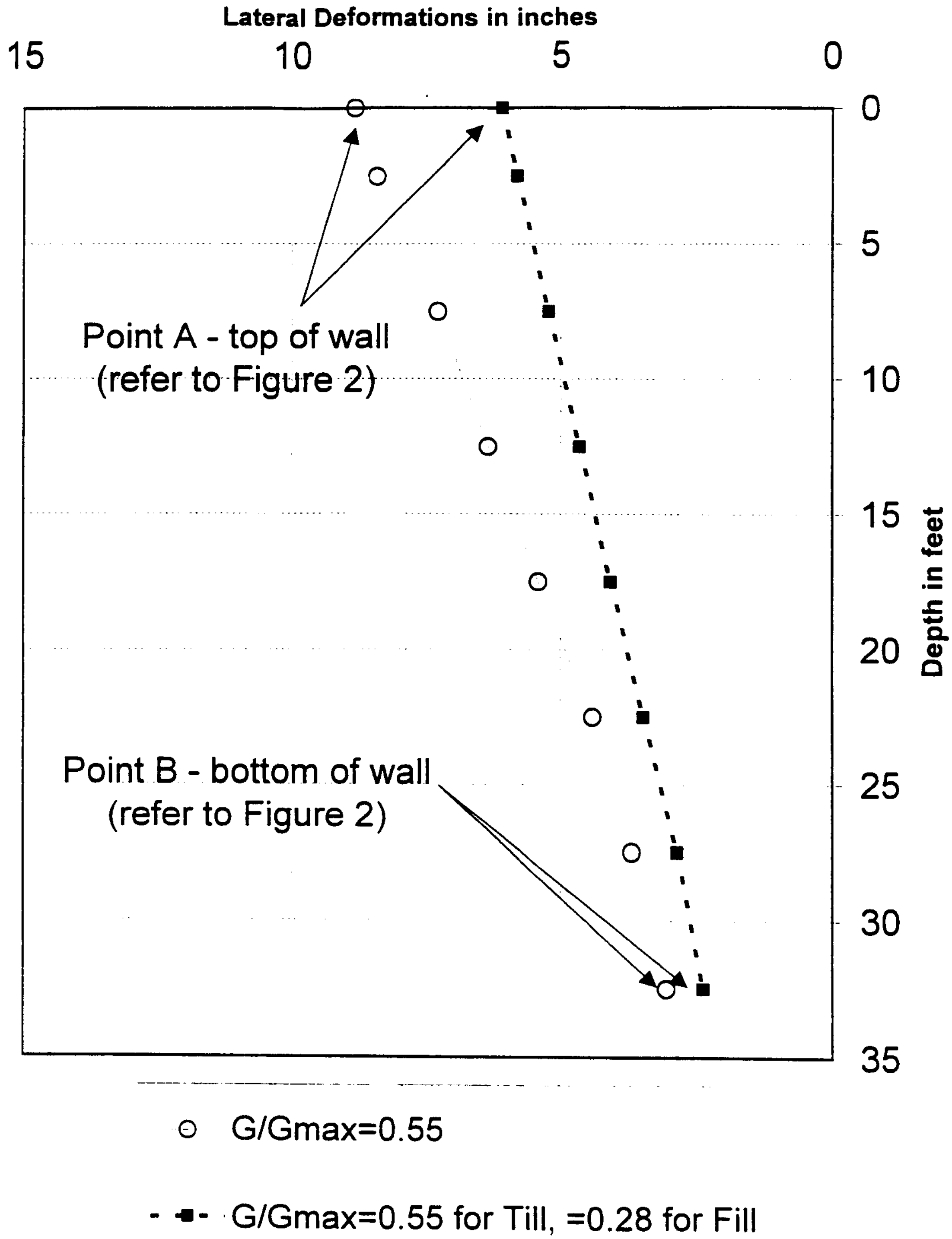

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Figure 3
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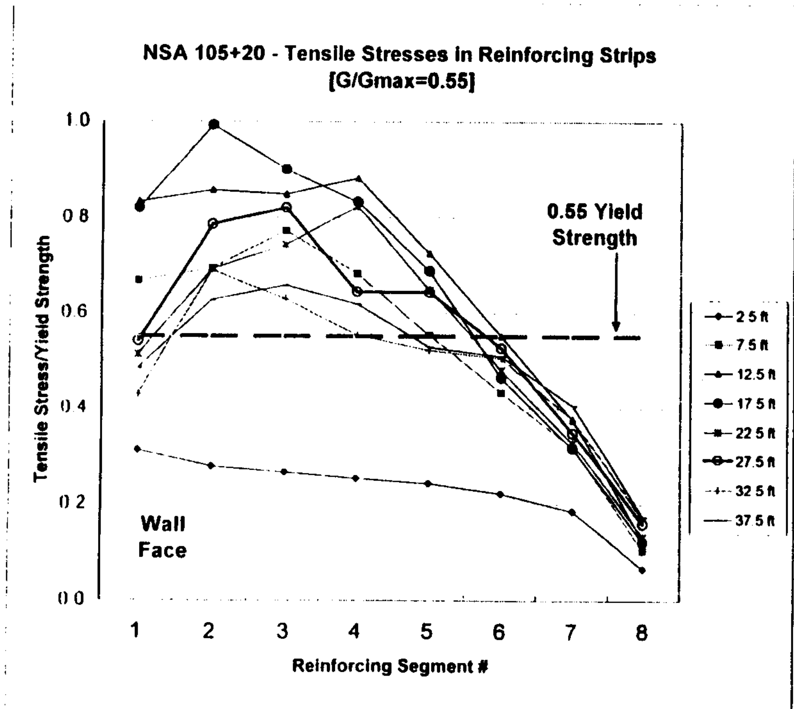
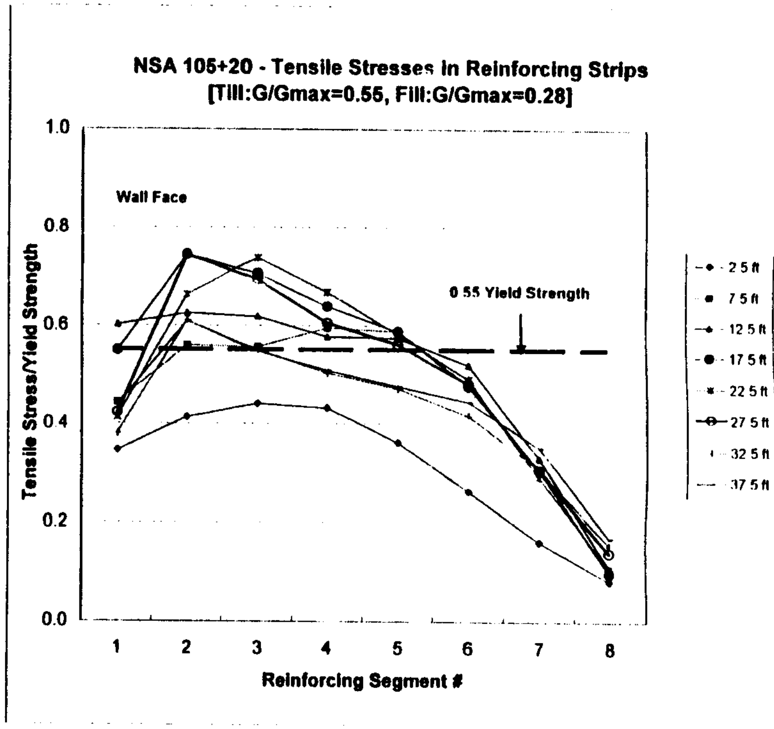
Comparison of Tensile Stresses





Note: Each reinforcing strip was divided into 8 length segments in the FLAC analyses

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Third Runway
Figure 4