LA-UR -85-1284

CONF-850809-59

RECEIVED BY OSTI MAY 06 1985

LA-UR--85-1284

DE85 010705

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SUBMITTED TO JK Session
SMiRT 8 Conference
Brussels Belgium
August 19-23, 1985

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FORM NO 836 R4
ST NO 2629 5/81

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ABSTRACT

With the use of scale models, the Seismic Category I Structures Program has demonstrated consistent results for measured values of stiffness at working loads. Furthermore, the values are well below the theoretical stiffnesses calculated from an uncracked strength-of-materials approach. The scale model structures, which are also models of each other, have demonstrated scalability between models. The current effort is to demonstrate that the use of microconcrete and other modeling effects do not introduce significant distortions that could drastically change conclusions regarding prototype behavior for these very stiff, shear dominated structures.

INTRODUCTION

The Seismic Category I Structures Program sponsored by the Mechanical/Structural Engineering Research Branch, of the U.S. Nuclear Regulatory Commission (USNRC) is directed at evaluation of the seismic reponse of nuclear Category I reinforced concrete structures (exclusive of containment) in both the elastic an inelastic ranges of behavior. These structures are constructed mainly from low aspect ratio shear walls where the ratio of shear to bending deformation ranges between 1 and 10. The primary failure concern during seismic response is not necessarily related to the structure itself but, rather, to attached piping and equipment. The status of some of the results from the Seismic Category I Structures Program through the end of FY-84 (October 1984) has been described elsewhere in this conference proceedings [1]. Some of those results were also reported to the US nuclear civil structures community in Ref. [2] and were discussed in detail with the Technical Review Group (TRG) for this program. The TRG is composed of nationally recognized experts in the nuclear civil structures community and was assembled to aid in planning and to comment on the progress of the program. Two outstanding issues have been identified and will be discussed below.

SCALABILITY ISSUE

The experimental program plan was developed with the foreknowledge that scale model testing of reinforced concrete structures is a somewhat controversial issue in the U.S. civil engineering community, particularly when the structures are loaded into the inelastic range. The similitude requirements for our models were carefully considered and discussed in detail in Ref. [3]. The experimental plan incorporated both static and seismic testing-to-failure of scale model Category I box-like structures as well as tests on isolated shear walls. The isolated shear wall tests were carried out first; they were then followed by static and seismic tests on one and two story box-like structures. To verify that the scaling relationships could be used to translate test results to different size structures and to obtain general structural behavior, two 1/30 scale and one 1/10 scale models of two-story diesel generator building structures were seismically tested. The first 1/30 scale model structure was tested to aid in the development of the test program for the 1/10 scale structure. After the 1/10 scale model tests, the second 1/30 scale model was tested in a manner similar to the 1/10 scale model. The results to date indicate that the scaling relationships that were developed adequately predict the behavior of different size structures.

To illustrate this point, Fig. 1 compares data taken from tests on a 1/30 scale model diesel generator building (30-13-2 and 30-11-2) and one 1/10 scale model (CERL No. 2). When the measured first mode frequency is normalized by the frequency scale factor, N_f, and the peak acceleration is normalized by the acceleration scale factor, $N_{\ddot{y}}$, the data can all be plotted on the same curve. In this notation, the subscript with the scale factor N means the ratio of the prototype subscript scale to the model subscript scale. In addition, the models had the appropriate added masses and the base motion was properly frequency scaled so that the 1/30 scale structure is a true 1/3 scale model of the 1/10 scale structure while both structures are models of the assumed prototype. When the data are illustrated as in Fig. 1, the prototype behavior is shown directly, while the individual model data require knowledge of the scale factors (1/30 scale: $N_f = 1/11.8$, $N_{\ddot{y}} = 1/4.6$ and 1/10 scale: $N_f = 1/6.8$, $N_{\ddot{y}} = 1/1.6$).

Clearly, the scalability of the two different sized models is demonstrated, but because both models are made of microconcrete with simulated rebar, scalability to the prototype structure is still an issue. Part of the current effort is to verify that the results are not severely distorted by the use of microconcrete and model rebar.

THE STIFFNESS DIFFERENCE ISSUE AND ITS IMPLICATIONS

A further issue raised by this program is demonstrated in Fig. 2. This figure shows the measured data (both static and dynamic) taken during this program that can be used to deduce the stiffness of the structure. Each measured value has been normalized by the structure's theoretical stiffness value calculated from an uncracked cross section strength-of-materials approach and plotted as a function of the concrete modulus, E_c. This modulus is obtained from the equation $E_c = 57000 \sqrt{fc'}$ as recommended in ACI 349 for normal weight concrete. With the exception of a single point (which happens to be a "wet" test in an aging study) the data consistently show that measured stiffnesses are a factor of 2-1/2 to 4 lower than the theoretical at this load level. The TRG notes the following:

1. Design of these structures is based on the uncracked cross section calculation and the designer may or may not "reduce" the stiffness. In any case, linear dynamic analysis of the structure based on this value of stiffness (reduced or not) is used to establish the floor and wall response spectra for attached equipment and piping. The design and safety of this equipment and piping is based on these spectra.
2. Safety analyses and determination of the safety margin are carried out using the theoretical stiffness, recognizing that other conservatisms probably compensate for any error. However, if the natural frequency of a Category I structure is shifted downward by as much as a factor of two and further structural degradation reduces its natural frequency even lower, then margins supplied by these conservatisms disappear rapidly.
3. The stiffness values reported in this program (as well as requested in some of the literature) are reduced from the theoretical value by as much as 3 or 4 or more depending upon the working load level. On

the other hand, values reduced by 20% or less have been indicated in other parts of the literature. The values determined dynamically in this program have consistently been lower than those that we have found statically. However, preliminary indications are that this is because the seismic loadings we have used are relatively large compared to the first cracking seismic load.

After making these three observations, the TRG raised a number of questions including the following. How credible is the data coming out of this program? What is the effect of using microconcrete and model rebar? What is the appropriate value of stiffness to report? Should it be a function of load level? What value is best used in a linear dynamic analysis of the structure? Have the equipment and piping in existing buildings been designed to the incorrect response spectra? If so, are there safety and retrofit issues that need to be addressed? How do we educate industry if this problem proves to be a significant one?

CREDIBILITY EXPERIMENTS

These concerns have lead the TRG to recommend that a series of credibility experiments be carried out using both large and small scale structures. For the large scale structures, the TRG set priorities on the design. Their recommended "ideal" structural characteristics in order of decreasing priority are as follows:

1. maximum predicted first mode natural frequency = 30 Hz,
2. minimum wall thickness = 4 in.,
3. height to depth ratio of shear wall ≤ 1,
4. actual #3 rebar for reinforcing,
5. realistic material for aggregate,
6. 0.1 to 1% steel (0.3% each face, each direction ideally),
7. water blasted construction joints to assure good aggregate frictional interlock.

They further suggested that the best plan is to build two of these structures and make them as identical as possible. The first should be tested quasistatically and cyclically to failure. The second should be tested dynamically.

Following these recommendations and after analyzing a number of potential designs, the structure shown in Fig. 3 was proposed for fulfilling the design requirements. Table I gives some of the details of this structure. Following discussions of a number of questions relating to the details and the potential of anomalous response (out of plane bending of walls, torsion, etc.) of the structure, the decision was made to construct and test this particular configuration and scale models of it.

TABLE I

COMPUTED CHARACTERISTICS OF THE TRG MODEL STRUCTURE

$I_{\text{Uncracked transformed section}}$	=	2.06×10^6 in.^{4}
$A_{\text{Effective shear}}$	=	379 in.^{2}
Area total	=	1288 in.^{4}
Total uncracked bending stiffness	=	3.5×10^7 lb/in.
Shear stiffness	=	5.3×10^6 lb/in.
Total stiffness	=	4.6×10^6 lb/in.
Max dead weight normal stress	=	29 psi
Max shear stress in flange at 5 g due to assumed 5% torsion (approx.)	=	35 psi
Total concrete	=	6 yards
Total added weight	=	37,600 lb
Total weight	=	60,800 lb

CLOSURE

By the time this paper will be given two of the small model structures will have been tested. Both low-load-level static and dynamic tests as well as "working load" level and higher load level tests will be carried out on these structures. The data from these credibility experiments are expected to contribute significantly to resolving both the scalability and stiffness difference issues that have been raised for seismic Category I structures.

REFERENCES

1. Dove, R. C., Endebrock, E. G., Dunwoody, W. E., and Bennett, J. G., "Seismic Tests on Models of Reinforced-Concrete Category I Buildings," 8th International Conference on Structural Mechanics in Reactor Technology, Brussels Belgium, August 19-23, 1985.

2. Endebrock, E. G., Dove, R. C., and Anderson, C. A., "Seismic Category I Structures Program," Proceedings of the 12th Water Reactor Safety Research Information Meeting, October 22, 1984, Washington, DC.

3. Dove, R. C., "Scale Modeling of Reinforced Concrete Category I Structures Subjected to Dynamic Loading,"

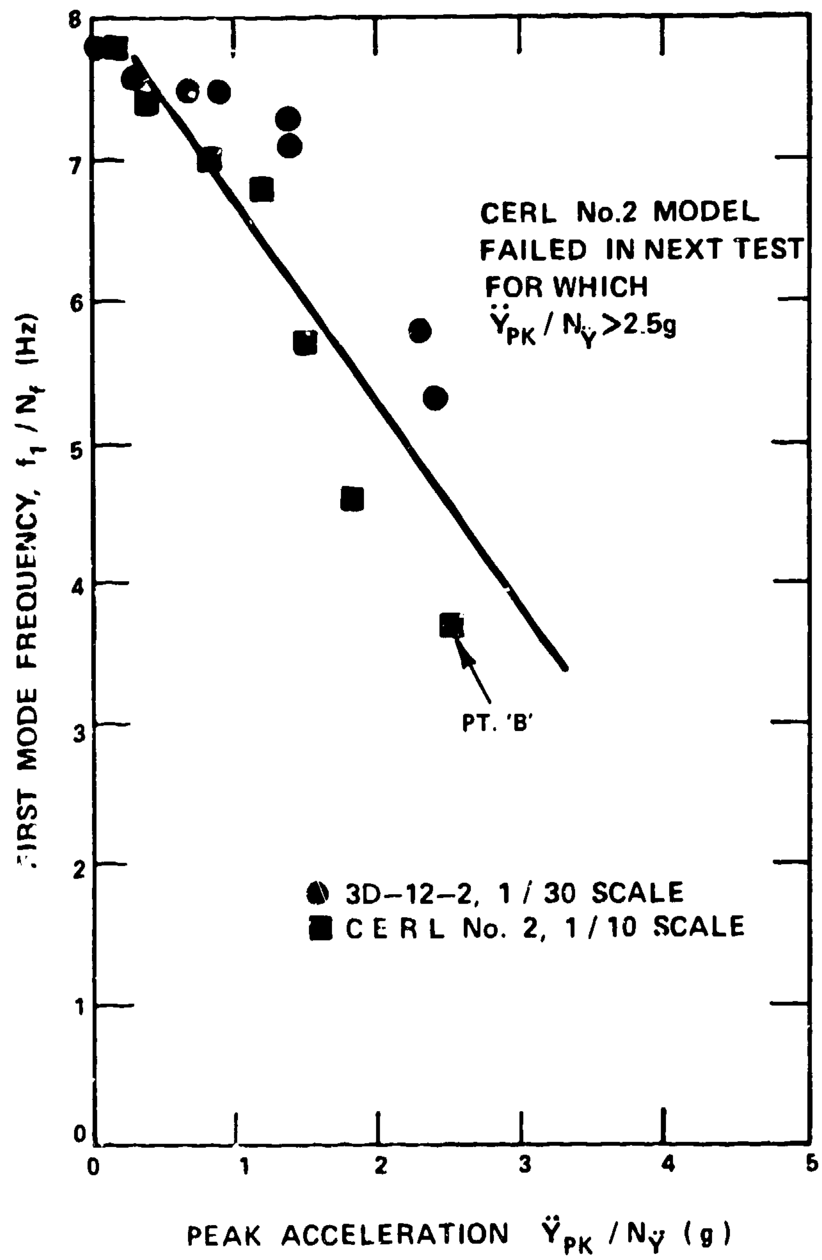

Fig. 1. Data illustrating the first mode frequency shift as the model structures were progressively damaged by increasing peak seismic base accelerations.

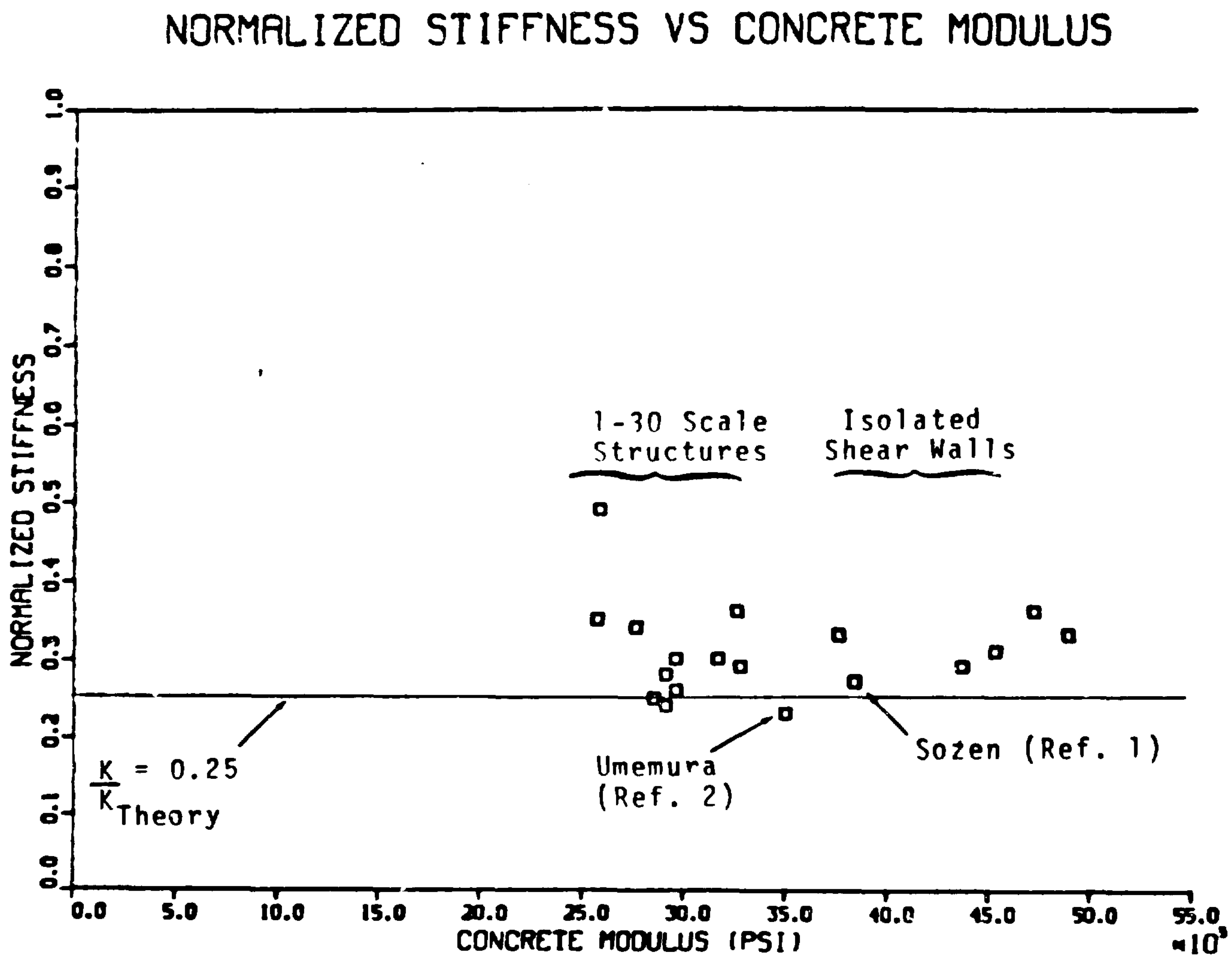

Fig. 2. Normalized stiffnesses versus concrete modulus from this program and other literature values.

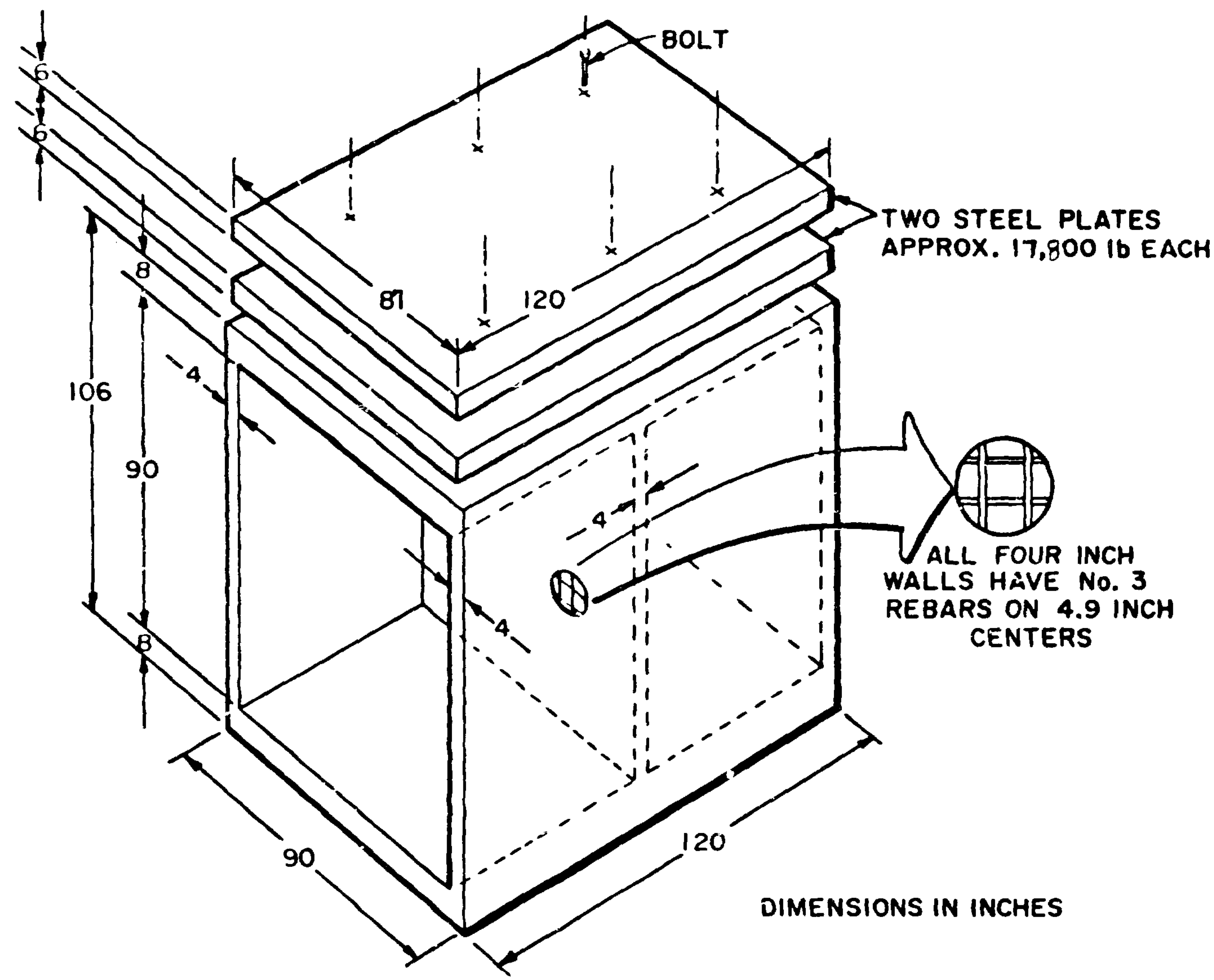

Fig. 3. TRG structural test model.