

DAMAGE PREDICTION FOR LOW-RISE BUILDINGS

by

John A. Blume^I and Roger E. Scholl^{II}

SYNOPSIS

Experimentally obtained low-rise building research findings applicable to two distinct procedures for predicting damage are described. Three types of studies are being conducted: (1) vibration tests of real buildings; (2) laboratory tests of structure elements; and (3) analysis of motion and damage data obtained from actual ground motion situations. The two prediction methodologies are: (1) a mass-spring modeling procedure wherein response is calculated and appropriate structure-element damage criteria are used to predict damage; and (2) a more direct procedure that involves the development of ground motion-damage relationships. The experimental findings are used in the two methodologies to compare their respective damage predictions. Conclusions are that the predictions compare well enough such that confidence in both procedures is enhanced.

INTRODUCTION

Considering the great number of low-rise buildings exposed to earthquake motion, relatively little has been done regarding the investigation of their susceptibility to damage. John A. Blume & Associates has recently undertaken an intensive study of low-rise buildings for the United States Atomic Energy Commission (USAEC) in connection with its safety measures for underground nuclear explosions. The objective of this work is to improve the technology for predicting damage to low-rise buildings subjected to ground motion. This paper gives a brief description of some of the findings and developments that have thus far resulted from that study.

The development of procedures for predicting structure damage caused by ground motion can be achieved from two somewhat distinct approaches. One involves evaluating the properties of individual structure members for the purpose of developing dynamic models that can be used to predict response. Then appropriate structure element damage criteria are used to predict damage. This is generally referred to as the theoretical procedure. The second and more direct approach simply involves the collection and correlation of appropriately synthesized ground motion and accompanying structure damage data. This is most appropriately designated the empirical procedure. The parameters involved in these methodologies can be identified either deterministically, probabilistically, or by a combination of the two.

^IPresident, John A. Blume & Associates, Engineers, 130 Jessie Street, San Francisco, California 94105

^{II}Director of Research, John A. Blume & Associates, Engineers, Research Division, 2765 South Highland Drive, Las Vegas, Nevada 89109

EXPERIMENTAL INVESTIGATIONS AND FINDINGS

The investigations conducted for the AEC have been directed toward obtaining data that can be injected into both of the above described methodologies. Work has been done simultaneously on: (1) vibration tests of real buildings; (2) laboratory tests of structure elements; and (3) analysis of motion and damage data obtained from actual ground motion situations.

Vibration tests of real low-rise buildings are being conducted to determine their dynamic response characteristics -- frequencies, mode shapes, and damping. Documented results¹ and other available data from vibration test and ground motion response show that most one- and two-story wood-frame and masonry residential buildings have fundamental mode periods in the range of 0.05 to 0.2 seconds. These data also yield equivalent viscous damping values in the range of 4% to 10% of critical. The data were obtained for interstory racking distortions of 0.05 cm or less. Although mode shape data presently available, are insufficient for establishing quantitative conclusions, it does show that foundation rocking and translation are more significant factors for stiff masonry buildings than for the more flexible wood-frame buildings. For wood-frame buildings on firm alluvium having a fundamental period of 0.2 seconds or longer, foundation translation and rocking effects are negligible.

Laboratory cyclic-racking tests of typical wall panels have been conducted to determine stiffness and damping as well as damage mechanisms and thresholds.² The wall panels tested were 8-foot x 8-foot sections. Stiffness results are too complex to discuss in this brief paper. Equivalent linear viscous modal damping calculated from the cyclic-racking tests is in the range of 10% to 20% of critical -- with a strong tendency toward 15%. The interstory displacements in these tests varied from 0.08 cm to 2.5 cm. The lower values of damping are associated with the lower values of interstory displacement. Damage has been observed at displacements as low as 0.25 cm.

Ground motion and damage data obtained from the RULISON underground nuclear explosion gas stimulation experiment³ were analyzed for the purpose of developing motion-damage relationships for low-rise buildings. The damage mostly involved minor wall cracking and toppling of loose chimney bricks. A total of approximately 1400 buildings in five towns subjected to spectral acceleration in the range of 0.06g to 0.9g were included in the study. In analyzing these data,⁴ the ground motion was characterized by 5% damped spectral acceleration, the buildings were idealized as single-degree-of-freedom systems having fundamental periods in the range of 0.05 to 0.2 seconds, and the damage was identified by type, as indicated in Figure 1, and in terms of a damage ratio (DR). For a set of buildings subjected to a given spectral acceleration, DR equals the ratio of damaged buildings to the total number of buildings. The envelope of the two horizontal components of spectral acceleration, S_{ae} , averaged over the period band of 0.05 to 0.2 seconds, was used to arrive at a distinct spectral acceleration. Figure 1 shows the best-fit lines⁴ derived from the analyzed data.

RECONCILIATION OF THEORETICAL AND EMPIRICAL PREDICTIONS

A simple but meaningful evaluation of the motion-damage relationships in Figure 1 can be made by comparing them with a damage prediction using the theoretical procedure wherein response is calculated. For this comparison, consider an example damage prediction for a one-story wood-frame building having a fundamental period of 0.1 seconds assumed to behave as a single-degree-of-freedom system (i.e., fixed base) with 5% equivalent viscous damping. By applying a criterion that wall damage will occur for a racking displacement (foundation to eave relative displacement) of 0.25 cm, the spectral acceleration, S_a , for onset of damage can be determined in Figure 2. By locating the intersection of the 0.1 second period vertical line with the 0.25 cm relative displacement, the onset of wall damage is found to occur for a spectral acceleration, $S_a = 1.0g$ and is shown as point 1 in the figure. This wall racking damage criterion cannot be considered as an absolute number but rather, as an average. In the racking tests some panels were damaged at racking displacements slightly under 0.25 cm, while for others, threshold damage occurred at greater relative displacements.² Moreover, the tests showed that for displacements an order of magnitude less, i.e., 0.025 cm, there was no detectable damage but for displacements an order of magnitude greater, i.e., 2.5 cm, damage was quite severe. These latter displacement values are designated as points 2 and 3, respectively, in Figure 2. Figure 2 also shows some of the motion-damage statistics obtained from the RULISON data. For spectral accelerations equal to 1.0g, the overall building damage ratio (DR) is 55% and the damage ratio for interior walls (DRw) is 35%. For 0.1g, DR and DRw are 4% and 2% respectively. Point 4 in Figure 2 represents the motion intensity at which damage will probably not be seen.

CONCLUSIONS

Based on a comparison of the empirical ground motion-damage relationships derived from the RULISON underground explosion experiment (shown in Figure 1) with the damage that might be predicted theoretically via a response analysis (illustrated in Figure 2), both appear to provide reasonably sound bases for predicting damage to low-rise buildings.

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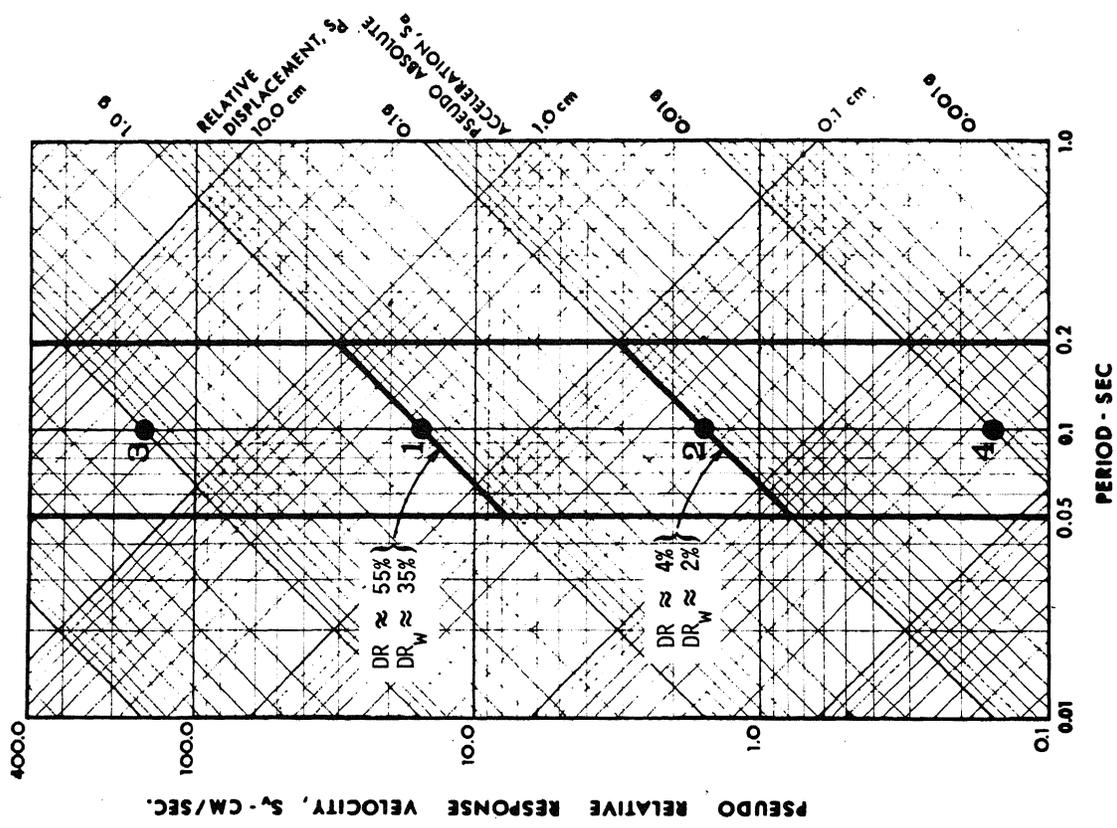


FIGURE 2

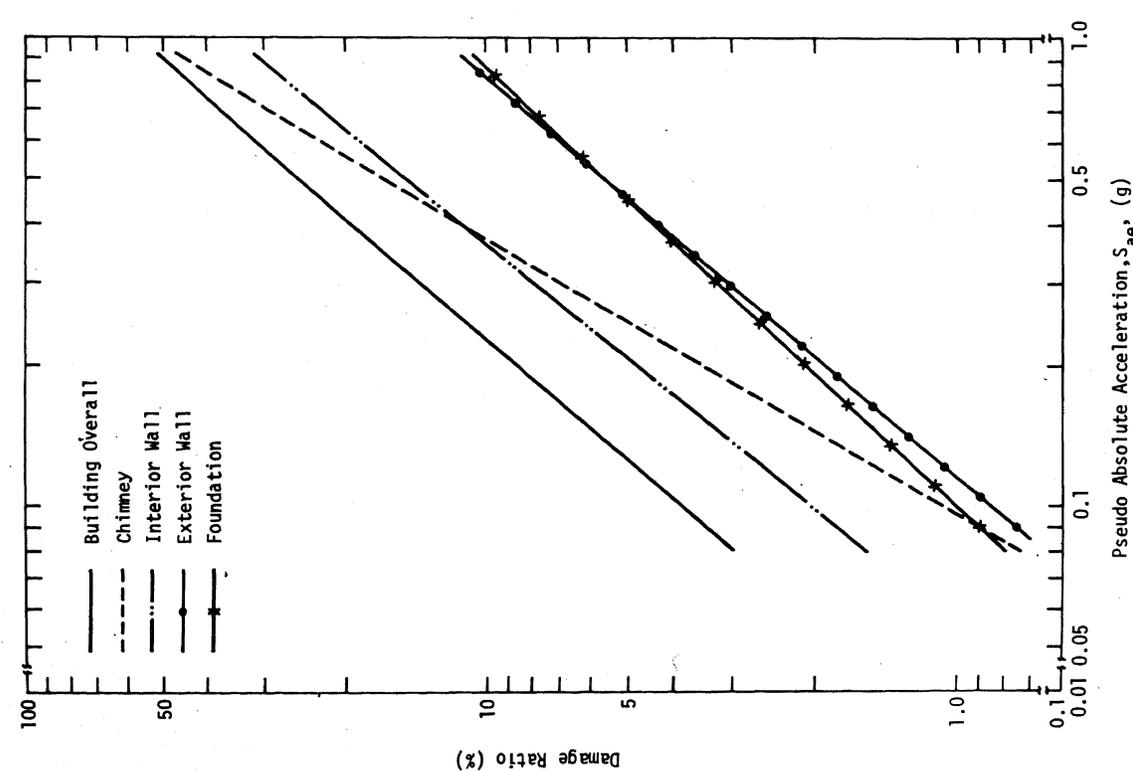


FIGURE 1 COMPONENT DAMAGE RATIO VS SPECTRAL ACCELERATION (RULISON)