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State-of-the Art Report
SCALE EFFECTS IN STATIC AND DYNAMIC MODEL TESTING OF STRUCTURES

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SUMMARY

This paper summarizes basic information available in the literature on scale effects in commonly used experimental procedures in earthquake engineering research. An evaluation of the effects of scaling of length and/or time on the behavior of test specimens is presented for different experimental methods. Material size and strain-rate effects are discussed, as well as scale effects due to fabrication of test specimens at reduced sizes. Emphasis is placed on scale effects in steel and reinforced concrete structures, with some attention being paid also to masonry and adobe structures.

INTRODUCTION

In the context of this discussion, scale effects include all response distortions that occur when one or more of the basic dimensional quantities in the FLTθ (Force-Length-Time-Temperature) system are scaled in an experiment. In earthquake engineering research, scale effects occur in quasi-static and pseudo-dynamic experiments, in which time is scaled, and in reduced-scale model experiments in which length is scaled and, as a consequence, force and time have to be scaled as well.

In dynamic model tests the scaling laws for force, time, and other dependent dimensional quantities can be derived through dimensional analysis (Ref. 1). Table 1 (next page) summarizes scaling laws for three types of models that may be suitable for seismic response studies involving inelastic material behavior. The three quantities underlined in every row are the basic quantities selected by the model designer. The quantity l_r denotes the ratio of model-to-prototype length.

As this table shows, true replica models (column 1) require a material whose specific stiffness E/ρ follows the same scaling law as the length dimension. Since for most practical purposes such materials, which also have to simulate stress-strain properties in the inelastic range, cannot be found, true replica models have few applications in seismic testing of structures. Whenever possible, structural models are made of prototype or prototype-like material (e.g., microconcrete) in order to minimize distortions of basic material properties. Thus, reduced-scale models are usually of the types identified in columns 2 and 3 of Table 1.

This paper addresses only scale effects that occur in models, whether in prototype size or at reduced scales, which are made of prototype-like materials.

Included in this discussion are models of steel, reinforced concrete, masonry, and adobe structures.

Table 1 Scaling Laws for Dynamic Models

Physical Quantity		Model type True replica model	Model type Artificial mass simulation (prototype mat.)	Model type Gravity forces neglected (prototype mat.)
		(1)	(2)	(3)
Length	l	l_r	l_r	l_r
Time	t	$l_r^{1/2}$	$l_r^{1/2}$	l_r
Frequency	ω	$l_r^{-1/2}$	$l_r^{-1/2}$	l_r^{-1}
Velocity	v	$l_r^{1/2}$	$l_r^{1/2}$	1
Grav. accel.	g	$\underline{1}$	$\underline{1}$	neglected
Acceleration	a	1	1	l_r^{-1}
Mass density	ρ	E_r/l_r	*	$\underline{1}$
Strain	ε	1	1	1
Stress	σ	E_r	1	1
Mod. of elasticity	E	$\underline{E_r}$	$\underline{1}$	$\underline{1}$
Spec. stiffness	E/ρ	l_r	---	1
Displacement	δ	l_r	l_r	l_r
Force	F	$E_r l_r^2$	l_r^2	l_r^2

* For lumped masses: $M_r = E_r l_r^2$

EFFECTS OF SCALING ON STRESS-STRAIN PROPERTIES

In general, materials have mechanical, thermal, electrical, and magnetic properties. In this paper we will deal only with mechanical properties and only those that define the state of stress and strain in the material. These properties may be time and temperature dependent (e.g., creep, shrinkage, and relaxation), vary from point to point (inhomogeneity), and be direction dependent (anisotropy). They also describe the interaction between different directions (Poisson's ratio) and neighboring points (e.g., strain gradient effects).

This section presents information on scaling effects that can be deduced directly from basic material tests and that illustrate the effects of time scaling (strain-rate effects) and length scaling (size effects) on the uniaxial stress-strain diagram and on commonly referenced material parameters. Additional information on time and size scale effects on structural response of elements will be presented later.

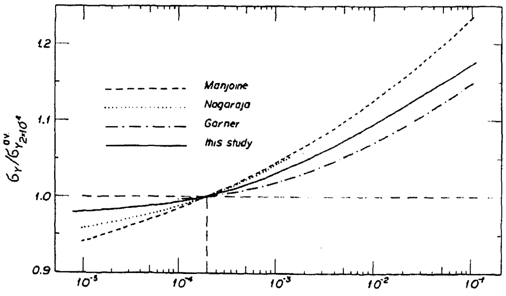

Fig. 1 Effect of Strain-Rate on Yield Strength of Structural Steel (Ref. 1)

Strain-Rate Effects Considerable research has been devoted to the influence of the speed of testing on the stress-strain properties of structural steel (e.g., Refs. 1 to 4). Qualitatively, all studies led to the same general conclusions, which are: the yield strength increases with an increase in strain-rate, the tensile strength increases also, but to a much smaller extent, and the modulus of elasticity remains essentially unchanged.

Quantitatively, the differences between the reported test results are large as can be seen from Fig. 1, which shows four regression lines for the effect of strain-rate on the yield strength of mild steel. These differences are attributed primarily to variations in test control (strain vs. stroke control) rather than to inherent differences in material properties. The solid line (Ref. 1), which was obtained from 24 tests that showed very little scatter around the regression line, appears to be a reasonable compromise among all reported test results. Using this line, the effect of strain-rate on the yield strength of structural steel can be expressed by the following equation:

$$\sigma_y/(\sigma_y)_{2x10^{-4}} = 0.973 + 0.45\dot{\varepsilon}^{0.33} \tag{1}$$

Interesting results have been reported in 1982 on the effect of strain-rates on the stress-strain diagram of reinforcing steel (Ref. 5). This study shows a much smaller effect of strain-rates on the yield strength of reinforcing steel (see Fig. 2) than for structural steel. Surprisingly, the study shows a larger effect on the tensile strength than the yield strength (see Fig. 3). Reference 5 gives also complete stress-strain diagrams at different strain-rates, which were deduced from the stroke-controlled experiments. Typical examples are shown in Fig. 4.

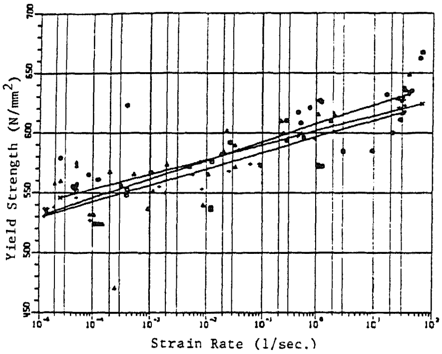

Fig. 2 Effect of Strain-Rate on Yield Strength of Reinforcing Steel (Ref. 5)

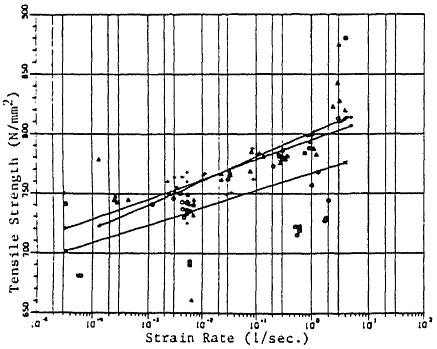

Fig. 3 Effect of Strain-Rate on Tensile Strength of Reinforcing Steel (Ref. 5)

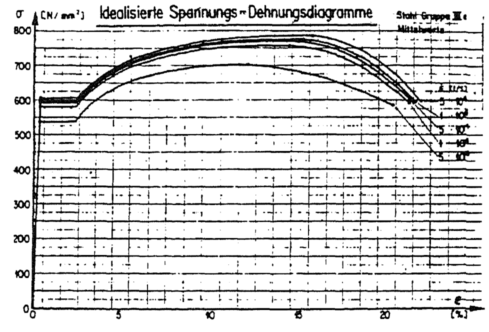

Fig. 4 Stress-Strain Diagrams of Reinforcing Steel at Different Strain-Rates (Ref. 5)

For concrete, many researchers have reported on the effects of loading rates on the properties of both prototype concrete (e.g., Refs. 6,7) and microconcrete (e.g., Refs. 8,9). Again, the results are qualitatively similar but quantitatively scattered because of variations in material properties and loading rate control. Typical results for microconcrete are shown in Figs. 5 and 6 (Ref. 9). Figure 5 illustrates the increase in compressive strength f_c' and initial stiffness with an increase in strain-rate. Figure 6 shows a regression line that quantifies the effect of strain-rate on the compressive strength. This regression line, which was obtained from more than hundred strain-rate tests, can be expressed by the following equation:

$$f_c'/(f_c')_{2x10^{-4}} = 1.478 + 0.1815 log\dot{\varepsilon} + 0.0145(log\dot{\varepsilon})^2 \tag{2}$$

For prototype concrete the reported strain-rate effects are usually somewhat smaller than for microconcrete. Thus, Eq. (2) appears to be a conservative estimate of these effects for prototype concrete. Comparing steel with concrete, it is evident that the strain-rates are considerably larger for the latter material.

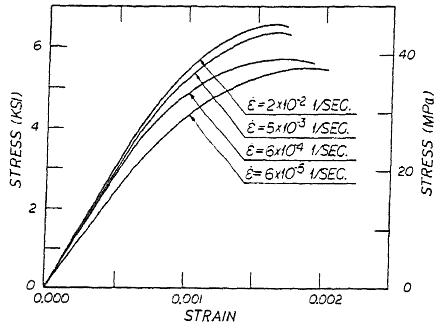

Fig. 5 Stress-Strain Curves for Microconcrete at Different Strain-Rates (Ref. 9)

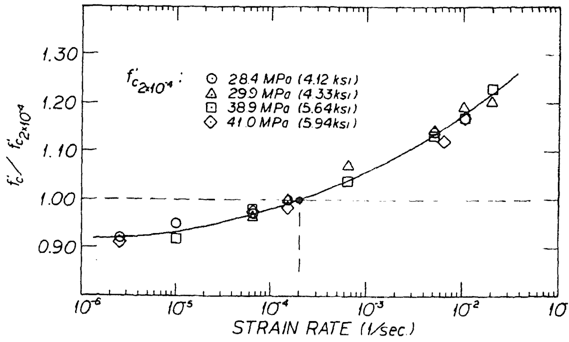

Fig. 6 Effect of Strain-Rates on Compressive Strength of Microconcrete (Ref. 9)

Size Effects Conflicting opinions are expressed in the literature on the importance of size effects in structural steel and other materials. However, there is considerable evidence that a reduction in specimen size leads to an increase in strength properties. This increase can be explained by the "weakest link" theory (Ref. 10) and is affected also by the difference in strain gradients of large and small specimens.

For structural steel, Richards (Ref. 11) proposed that the yield stress can be related to the volume of the test specimens and can be expressed by the equation

$$\sigma_y = \sigma_{y1}/V^{1/m} \tag{3}$$

where V is the volume of the test specimen, σ_{y1} is the yield stress for a specimen of unit volume, and m is a material constant. For the mild steel used in his study, Richards found m to be equal to 58 for a tension test and 11.7 for a bending test. The latter value is much smaller because of the high strain gradient in bending and suggests a tremendous size effect in bending. Pilot experiments reported in Ref. 12 do not confirm this low value of m and suggest a value that is closer to 40.

In Ref. 10 an extensive discussion is presented on the size effects in concrete. The effect of cylinder size on the compressive strength f_c' of prototype concrete is found to be small unless the diameter of the cylinder is smaller than 3 inches. For microconcrete the effect of cylinder size on f_c' is somewhat more pronounced. Size effects are, however, of much more importance for the tensile strength of beams tested in bending because of the high strain gradient. Fig. 7 (Ref. 13) illustrates this effect with results obtained from third-point loaded beams of span:depth:width ratios of 12:2:1.

In part, the size effects occurring in small-scale models can be overcome by performing reference material tests on specimens compatible in size with the smallest dimension of the elements in the model structure. However, the distortions due to size effects depend on the strain gradient, which makes it difficult to account for size effects in model tests governed by flexure.

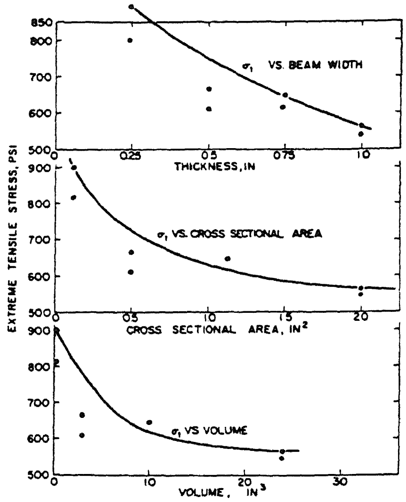

Fig. 7 Effect of Specimen Size on Flexural Tensile Strength of Microconcrete (Ref. 13)

EFFECTS OF SCALING ON THE RESPONSE OF MODELS OF STEEL STRUCTURES AND ELEMENTS

Distortions in the response of reduced-scale models may occur due to a variety of sources in addition to the previously discussed material strain-rate and size effects. Even those effects have to be reevaluated in view of the fact that their influence has to be integrated over elements whose state of stress or strain is different from that encountered in the material tests. Other material properties (e.g., fatigue and fracture properties) and size effects in the model fabrication process have to be considered as well. Theses are the issues discussed in this and the following sections.

Scaling Effects due to Fabrication Scaling problems may occur during element fabrication and element assembly. Large-scale elements (in the order of 1:2) can often be bought off the shelf and should pose no scaling problems. Medium-scale elements (in the order of 1:3 to 1:6) are usually welded together from plate elements, which may cause camber, distortions, and a complex state of residual stresses. This may necessitate straightening and/or heat treatment which may result in a state of initial stress that is quite different from that existing in a hot-rolled section. The consequences on structural response simulation are expected to be minor in models that have to simulate inelastic behavior. A notable exception is buckling of columns of intermediate slenderness ratios, in which the residual stresses will affect the strength and post-buckling behavior. Similar problems exist in small-scale elements, which are usually machined from bar stock and are almost free of residual stresses.

A multitude of localized problems are usually generated in the process of assembling individual elements into structural configurations. These problems are much larger in small-scale models than in large or medium-scale models. An accurate simulation of bolted or welded connections is an almost impossible task. Welding is usually done by using the TIG process. With this process it is often not feasible to make welds small enough to satisfy similitude at small scales. An additional distortion caused by welding on small sections is due to the size of the heat-affected zone. Because the welding process produces a much larger molten pool in the model specimen than does corresponding welding in the prototype structure, the heat-affected zone in the model is a larger fraction of member length than in the prototype and will be subjected to higher temperatures. In addition to this more severe heating, the larger surface area to volume ratio of the model section results in more rapid cooling. This causes much larger residual fabrication stresses in the model and necessitates stress relieving, which in turn will cause a small and unknown state of residual stress.

There are additional reasons why similitude at weldments cannot be achieved. The shape, distribution, and size of initial imperfections cannot be reproduced at reduced scales. Thus, crack initiation and crack propagation cannot be simulated, whether the scale is 1:2 or 1:20. In addition, notch toughness and crack propagation rates in steel are sensitive to strain rates. The simple conclusion is that a simulation of phenomena associated with crack propagation and fracture should not be attempted with reduced-scale models.

Material Strain-Rate and Size Effects The previously presented data on strain-rate effects were obtained from uniaxial tension specimens loaded monotonically. Monotonic and cyclic load tests on flexural elements with controlled displacement rates have been reported by several investigators (e.g., Refs.14 to 16). In tests in which displacement was controlled by a sine-wave motion (Refs. 14 and 15), relatively little difference was noticed between the results of low and high frequency tests. The reason may be that in a sine-wave controlled test the displacement rate drops drastically as the displacement increases and correspondingly the strain rates drop as well.

In tests in which the displacement rate was kept constant during the loading and unloading excursions (Ref. 16), a increase in beam bending strength consistent with the material strain-rate data expressed by Eq. (1) was observed. In the test series reported in Ref. 16 bare steel beams as well as steel beams with a composite deck were tested. Figure 8 shows the results of monotonic tests with different displacement rates for two steel beams (S1 and S2) and two composite beams (C1 and C2). Figure 9 summarizes the displacement rate dependence of the beam bending strength for all tests. This figure shows that the displacement rate effect (a) is larger for the composite beams because of the presence of concrete which exhibits larger strain-rate effects, and (b) is larger for monotonic loading than for cyclic loading because cyclic workhardening compensates in part for strain-rate effects. Since displacement rates and strain rates are not linearly related in a nonlinear bending test, a direct correlation between the two rates is difficult to make. But the use of Eq. (1) together with estimates of measured strain rates given in Ref. 16 results in predictions of strength increases that match closely with those observed in this test series. Thus, the effects of displacement rates on structural response can be predicted from material strain-rate data.

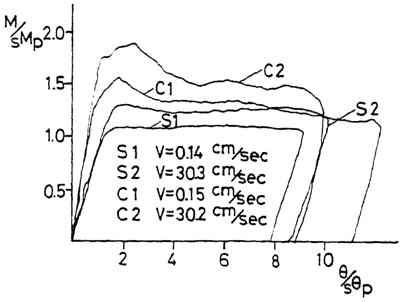

Fig. 8 Effect of Displacement Rates on Flexural Response of Beams (Ref. 16)

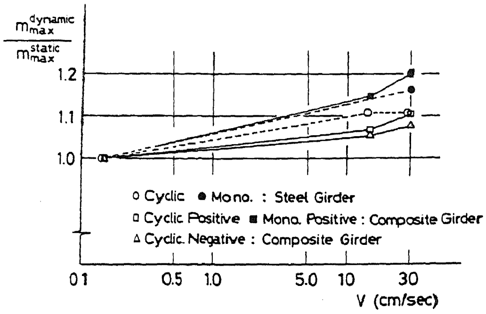

Fig. 9 Effect of Displacement Rates on Bending Strength of Beams (Ref. 16)

The effect of size scaling on the strength of structural steel elements depends somewhat on the strain gradient in the inelastic regions. In a series of 1:12.5 scale model tests of beam-column assemblies (Ref. 12) it was found that the bending strength was about 10% higher than was expected based on tests of identical prototype specimens. Since the reference yield strength for the model specimens was determined from reduced-scale tension specimens, these 10% come on top of the material size effect accounted for in the reduced-scale tension tests. Since this effect is also about 10%, the total size effect amounts to a strength increase of about 20%.

The material and element tests reported in the literature on size and strain-rate effects do not show a strong and consistent influence of scaling of size and time on the ductility and deterioration characteristics of steel elements. Where such effects are reported, they lead usually to an improvement in structural behavior as size is reduced and strain rates are increased. Compared to other scaling problems this influence appears to be small, except at connections where the previously discussed problems predominate.

EFFECTS OF SCALING ON THE RESPONSE OF MODELS OF REINFORCED CONCRETE STRUCTURES AND ELEMENTS

Scaling Effects due to Fabrication In the writer's experience, standard details of cast-in-place reinforced concrete elements and structures can be reproduced faithfully in models at scales as small as 1:15. Thus, fabrication problems are concerned primarily with proper simulation of initial conditions at the time of testing. This implies simulation of initial stresses and strains due to creep and shrinkage. Both phenomena cannot, and may not have to be, simulated in model tests whose objective it is to study the inelastic dynamic behavior of structures. Most suitably then, both creep and shrinkage stresses and strains should be eliminated to the extent possible. This is easily done for creep effects since reduced-scale models are light and can be loaded just before testing, but requires special precautions for shrinkage effects.

Since the surface-to-volume ratio in reduced-scale models is much larger than in prototype structures, shrinkage in models will occur at a much faster rate, and significant shrinkage cracks have to be expected soon in models permitted to dry out. Thus, model specimens should be stored at close to 100% humidity as long as possible and should be sealed (e.g., with shellac spray) once the surface has dried after removal from the humidity room. This will prevent moisture loss and subsequent shrinkage cracking.

Simulation of Bond Bond similitude is and will remain a major problem in reduced-scale model testing of R/C structures. The force transfer between concrete (or microconcrete) and the reinforcement will affect not only the resistance against pull-out but also the spacing between direct tension cracks and the occurrence of secondary failure mechenisms such as longitudinal splitting along bars close to the surface.

Bond characteristics depend on both component materials, and the variability in model concrete (microconcrete) makes it difficult to give a quantitative assessment of bond scaling effects. Certainly, the type of model reinforcement has the largest effect on bond characteristics. Plain wires, chemically treated wires, and threaded, knurled, or cold-rolled wires have been used for this purpose. For many reasons cold-rolled wire reinforcement that simulates the protrusions existing in prototype reinforcement is the most suitable type of model reinforcement. It has been used with much success in a 1:12.5 scale model study of R/C joint and frame assemblies for which prototype test results were available for comparison (Refs. 17 and 18). Reference 18 contains a detailed discussion of the cold-rolling procedure and the type and heat treatment of the steel wire used for this purpose.

Simulation of Cracking It is well established that the number of cracks decreases with a decrease in model size. However, the prototype crack patterns are maintained in well designed and constructed models and the effects of the smaller number of cracks on the inelastic strength and deformation characteristics are usually found to be small. An example of the dependence of the number of cracks on the model size is given in Fig. 10 (Ref. 18). This figure illustrates the number of flexural cracks in the first story of a boundary element of a shear wall that was tested at full size as well as at four model scales (Ref. 19). It can be seen that the number of cracks decreases rapidly as the size of the test structure is reduced from full-size to medium scales. A much smaller reduction in the number of cracks is observed as the model size decreases from medium to small scales. Although the 1:12.5 scale model contains fewer than half the cracks of the prototype, the bending strengths of the two walls are within a few percent.

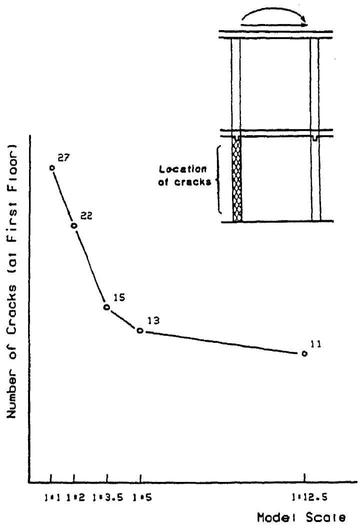

Fig. 10 Number of Cracks as a Function of Model Scale (Ref. 18)

Crack initiation is a function of the tensile strength of the concrete, which is increased at reduced scales. Crack spacing and width are both dependent on the bond between the two component materials. Reinforcement with properly spaced lugs will help in maintaining crack similitude. It is important also that model reinforcement simulates the strain hardening characteristics of the prototype rebars. This strain hardening allows the bars crossing a crack to develop tensile forces large enough to overcome the combined tensile strength of the uncracked concrete and the unyielded steel nearby and thus open new cracks rather than enlarge existing ones. By improving similitude of bond and strain hardening it will be possible to obtain crack patterns in models that more closely agree with those in their respective prototypes.

Strain-Rate Effects Results from cyclic load tests on R/C beams performed with different displacement rates are reported in Refs. 1 and 20. In Ref. 20 an increase of 20 percent in yield resistance of a beam was reported when the rate of loading was increased by a factor of 100. Smaller increases are reported in Ref. 1 in a series of small-scale model tests performed at displacement frequencies.of 0.0025, 2, and 10 Hz. Four beams were tested at each frequency. Representative load-displacement histories at the three frequencies are shown in Fig. 11. Three cycles each at two different displacement amplitudes were applied to each specimen. Only the first cycles at the two amplitudes are shown in the figure. The subsequent cycles led consistantly to noticeable strength deterioration. A relatively small effect of the cycling frequency on the strength is noticed at the smaller amplitude, however, considerably larger strength deterioration is evident for the quasi-static test (0.0025 Hz) during the first large displacement cycle. The effect of cycling frequency on strength deterioration is shown more clearly in Fig. 12 in which each point represents the mean of the peak loads from four tests. The peak loads in the small amplitude cycles (P_{11}, P_{12}, and P_{13}) are rather insensitive to the cycling frequency, whereas the peak load in the first large amplitude cycle (P_{21}) is affected considerably by the cycling frequency.

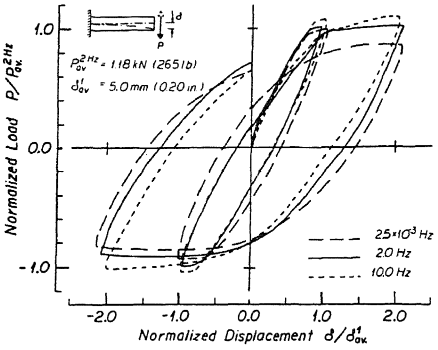

Fig. 11 Load-Displacement Hysteresis Loops for R/C Beams Tested at Different Frequencies (Ref. 1)

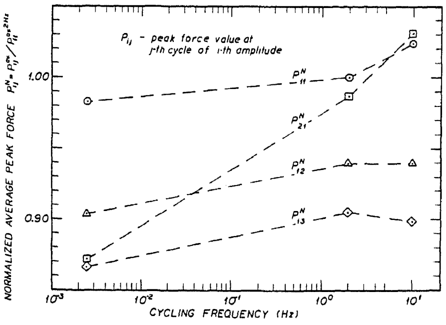

Fig. 12 Effect of Cyclic Frequency on Peak Loads in R/C Beam Tests (Ref. 1)

Figure 12 shows that the cycling frequency affects strength as well as strength deterioration. The data presented previously on material strain-rate effects may be useful to predict the effects on the undeteriorated strength of elements but do not help in predicting the effects of displacement rates on strength deterioration. This creates a problem that will always be present when the dynamic response of structural elements is predicted from "static" tests.

EFFECTS OF SCALING ON THE RESPONSE OF MODELS OF MASONRY AND ADOBE STRUCTURES AND ELEMENTS

Reduced-scale modeling of burned clay and concrete masonry as well as adobe buildings has received some attention in the literature (e.g., Refs. 21 to 23). The scaling problems discussed for R/C apply for these models as well, and additional problems are caused by similitude requirements at the mortar joints. Because of the variability in mortars, no quantitative conclusions can be drawn on scaling effects, but all reported results indicate a considerable increase in mortar strength and bond strength between mortar and brick compared to prototype behavior. The main reasons appear to be size effects due to the increased surface-to-volume ratio in models. The wet mortar dries in a relatively short time, thus increasing the mortar strength, and relatively more water penetrates from the wet mortar into the brick, thus increasing the bond strength. These combined effects will lead to a larger increase in strength quantities governed by tension (e.g., bending and "shear") than by compression.

A pilot study on strain-rate and size effects in adobe brick assemblies is reported in Ref. 23. When four small-scale beam specimens were loaded to failure at a rapid rate (0.04 seconds to failure), the mean strength of the beams increased by 9 percent compared to static load test results. This indicates that strain-rate effects are comparable to those in reinforced concrete elements. However, size effects are much larger and depend on the type of loading. In compression prism tests of full-scale and 1:3.8 scale models the increase in mean strength was 35 percent, whereas in beam bending tests it was 105 percent. The reasons for the differences are given in the previous paragraph. These results show that in reduced-scale models of masonry structures the strength increase depends on the failure mode and that an interpretation of test results must be based on reference strength values that are determined from companion material tests that simulate the same failure mode and are performed at the same scale as the model test.

EVALUATION OF SCALE EFFECTS IN DIFFERENT TEST METHODS

Quasi-Static Testing This method is the standard procedure for testing elements and subassemblies for the purpose of aquiring knowledge needed to derive design and detailing procedures. Usually, a predetermined displacement history is applied to the test specimen in a very slow manner, with many long pauses to inspect the specimen for visual damage. If prototype size specimens are used, the only scale effects result from scaling time compared to the dynamic response of the elements. All evidence found in the literature points to the conclusion that slow testing results in a decrease in strength and, at least for R/C and masonry structures, a clear increase in deterioration (e.g., Figs. 11 and 12). Thus, the results from these tests can be considered as being conservative for the derivation of design recommendations, provided that the predetermined displacement history covers the range of deformations the element may experience in a severe earthquake.

Pseudo-Dynamic Testing In this method a computer feedback system is used to predict the seismic displacement history for the test from the stiffness properties measured during previous load increments of the experiment. The intent of this method is to predict, as closely as possible, the response of a structure or substructure to one specific earthquake.

These displacement controlled tests are performed at time rates that vary from very slow to rates that approach the actual dynamic response (Ref. 24). Slow rate tests will experience the previously discussed time rate effects as well as an additional effect that may distort the predicted displacement response. Since slow testing leads to a decrease in strength and inelastic stiffness, the computer-predicted seismic response will be based on strength and stiffness quantities that differ from the true dynamic response.

In Ref. 25 an analytical study is reported that tries to predict the distortions in seismic response caused by different rates of loading. Figure 13 (Ref. 25) shows a typical result obtained for an SDOF system subjected to the NS component of the 1940 El Centro ground motion. The pseudo-dynamic and dynamic results are based on periods of the system of 80 and 0.4 seconds, respectively. This figure shows a considerable increase in predicted ductilities for the slow tests. However, it must be said that these predictions are based on a very conservative strain-rate model that predicts much larger strength increases than would be predicted from Eq. (1). The author believes that the true time rate effects

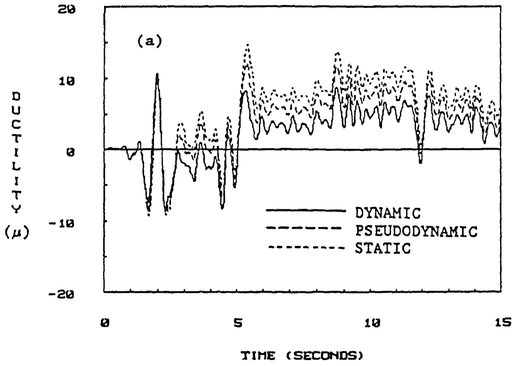

Fig. 13 Response Histories Based on Different Rates of Loading (Ref. 25)

are considerably smaller than indicated by this model. Clearly, these effects can be reduced further by performing a pseudo-dynamic test at as fast a rate as feasible.

Reduced-Scale Model Testing Results of this testing method are affected by scaling of time and size. If a quasi-static test if performed, the previously discussed strain-rate effects apply. If a shake table test is performed, the strain-rate effects are negligible because the scaling of time in reduced-scale models is not significant in seismic research (see Table 1).

Size effects due to model fabrication problems and material property distortions deserve always careful consideration. If their importance is recognized in model design, testing, and test result interpretation, reduced-scale models will yield valuable results. The experience of the writer is that the global elastic and inelastic response characteristics of complex structures can be simulated at model scales, even at rather small scales. This is where the advantage of small-scale models lies, as they permit the testing to failure of complex structural configurations in a controlled laboratory environment and at an affordable cost. An example of the kind of global simulation that can be achieved with small-scale models is illustrated in Fig. 14, which shows the base shear vs. roof displacement responses of the prototype and 1:12.5 scale model of the 7-story R/C frame - shear wall structure tested in the U.S.-Japan cooperative research program (Ref. 19).

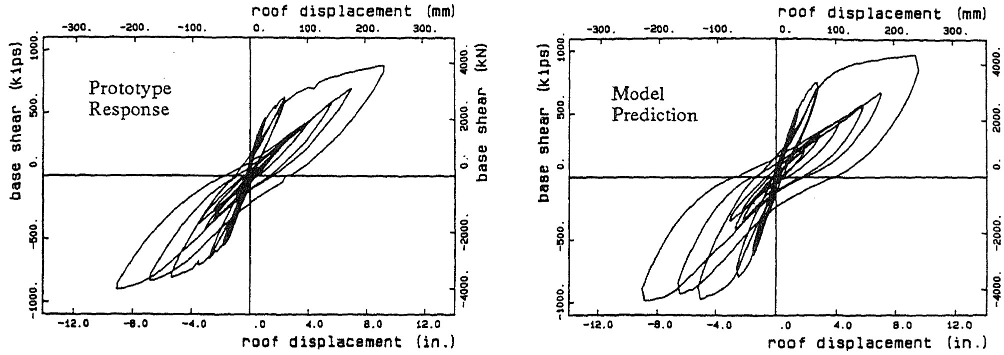

Fig. 14 Response of 7-Story R/C Frame - Shear Wall Prototype Structure and Model Prediction (Ref. 17)

The detailed localized response, particularly at connections and joints, can often not be reproduced adequately at reduced scales. This applies particularly to crack propagation problems in steel structures and deterioration characteristics in reinforced concrete structures. Figure 15 illustrates the latter on test results from a prototype and a 1:12.5 scale model of a R/C joint assembly (Ref. 17).

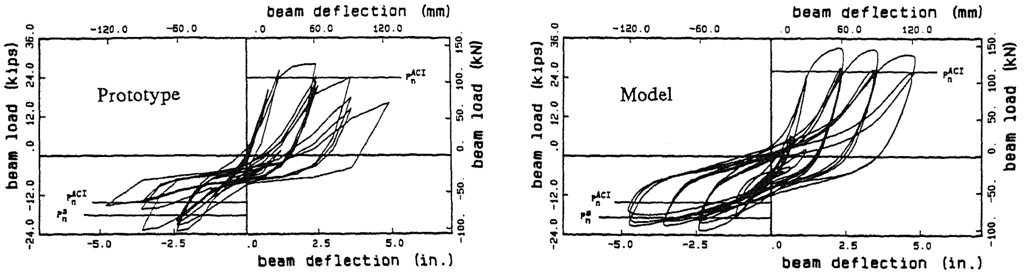

Fig. 15 Response of Prototype and 1:12.5 Scale Model of R/C Joint Assembly (Ref. 17)

The conclusion is that the application of reduced-scale models to the study of localized phenomena must be viewed with caution. In many cases the results would be misleading, particularly if they were used to derive design criteria. For this purpose only <u>full-size</u> specimens should be used. Unfortunately, in many cases this is not done. For instance, design criteria for steel beam-to-column connections and joints are based primarily on results that have been obtained from tests with small to medium steel W-sections, but are applied in the design of steel structures with jumbo-sections. Clearly, for jumbo-sections the test sections are reduced-scale models whose behavior may be affected by many of the scaling problems summarized here.

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