Comparison of P695 Studies for SpeedCore and Reinforced Concrete Walls

Validating seismic response modification factors used in the design of a lateral force resisting system requires both proper analysis and testing. These requisite studies generally occur before the factors can be incorporated into relevant standards (ASCE, NEHRP, AISC, etc.). Common practice is to implement the methodology described in *FEMA P695 Quantification of Building Seismic Performance Factors* for justification of the factors.

For reference, the three seismic response factors in question are:

- The seismic response reduction factor *(R)* accounts for system level ductility and inelastic behavior. In a general sense, the *R* factor reduces the seismic design forces calculated assuming elastic behavior. The higher the system level ductility, the higher the *R*-factor; However, ASCE 7 sets a maximum *R* factor of 8.
- The overstrength factor Ω_o accounts for the overstrength in the system between the assumed onset of inelasticity and the formation of the complete plastic (failure) mechanism due to material overstrength, structural redundancy, and other contributing factors.
- The displacement amplification factor C_d accounts for the amplification of the calculated elastic story drift of the lateral force system due to inelastic behavior.

In short, the P695 analysis process has demonstrated that SpeedCore has superior seismic performance to RC wall systems.

In fact, the *R* value for SpeedCore may be greater than 8, but it would be challenging to quantify that due to both constraints in the P695 analysis procedure and performance perceptions.

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Figure 1 shows these factors in terms of base shear ratio to story drift. Essentially, a high *R* value means a given structural system can dissipate more energy and allow a structure to behave in a ductile manner. For a designer, therefore, the *R* factor is arguably the most important because it determines the reduction in calculated lateral forces for a given structure. Thus, an *R* of 8 would mean the calculated seismic forces could be reduced by a factor of 8 in design.

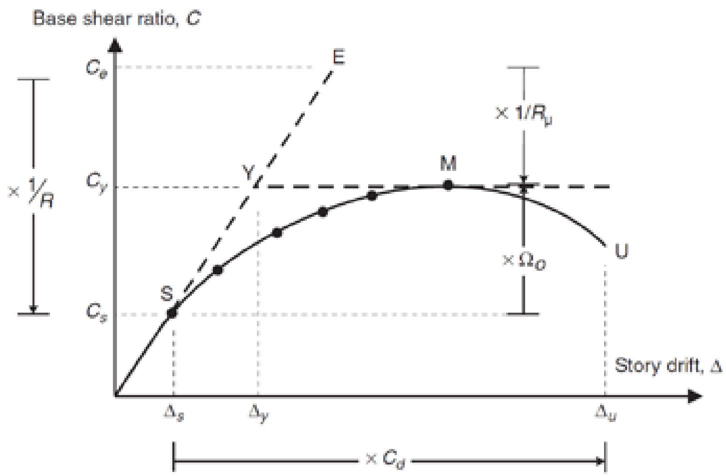


Fig. 1. Seismic response modification factors represented graphically.

Comparison of SpeedCore and Reinforced Concrete Walls

P695 studies have examined SpeedCore systems and reinforced concrete wall systems. As you can see, both systems show comparable seismic performance at first glance.

Table 1. Seismic Response Modification Factors for SpeedCore Systems and Reinforced Concrete Wall Systems

System	R	Ω_o	C_d
SpeedCore – uncoupled	6.5	2.5	5.5
SpeedCore – coupled	8	2.5	5.5
Reinforced Concrete (RC) wall	8	2.5	8

However, there are substantial differences between the systems with respect to both design philosophies and the P695 studies conducted to validate the response modification factors. Data from the P695 studies show more promising results for the seismic response of the SpeedCore system.

Differences in Analytical Models

SpeedCore study: two sets of models

Each study considered material and geometric nonlinearities with sets of numerical models that accounted for the various complexities of flexural behavior of the coupling beams and composite walls. Researchers performed Incremental Dynamic Analyses (IDA) on two different sets of nonlinear models in parallel to assess the sensitivity of the results. This robust validation of the proposed design provisions and seismic design coefficients and factors provides increased confidence in the study's results.

RC walls

Similar to the modeling techniques used to assess SpeedCore's performance, the RC wall study used numerical models that accounted for material and geometric nonlinearities, but it only considered one set of models instead of two. Researchers used fiber elements with linear springs to model wall piers and non-linear shear springs to model beam-column elements. These modeling techniques, along with assumed material models, helped capture the potential failure modes of the system, including flexural failure, shear failure, and axial failure.

Comparison

While there is nothing wrong with the analytical model implemented for the RC wall study, the extra set of models in the SpeedCore study allowed researchers to run parallel analyses and compare the results.

This further validation of the study's results provides more confidence that the models' behavior is representative of the way actual structures would behave.

Archetypes Analyzed and Results

SpeedCore

The SpeedCore P695 study analyzed three-story, eight-story, 12-story, 18-story, and 22-story archetypes, each considering 4 different coupled walls, for a total of 20 different archetypes. Researchers used an *R* value of 8 and C_d value of 5.5 before applying the P695 procedure to calculate Adjusted Collapse Margin Ratios (ACMRs) for all 20 archetypes.

Roughly speaking, an ACMR measures the resistance of a given structure to collapse. The higher the ACMR, the better. Researchers first calculate an acceptable ACMR based on uncertainty associated with earthquake records, design requirements, test data, and modeling assumptions. For FEMA P695, the ACMR at 10% likelihood of exceedance is calculated initially and then the ACMRs of the specific archetypes are calculated and compared. The idea is that the ACMR calculated for each archetype should exceed the ACMR at 10% likelihood of exceedance. Here's how each SpeedCore archetype fared.

RC Walls

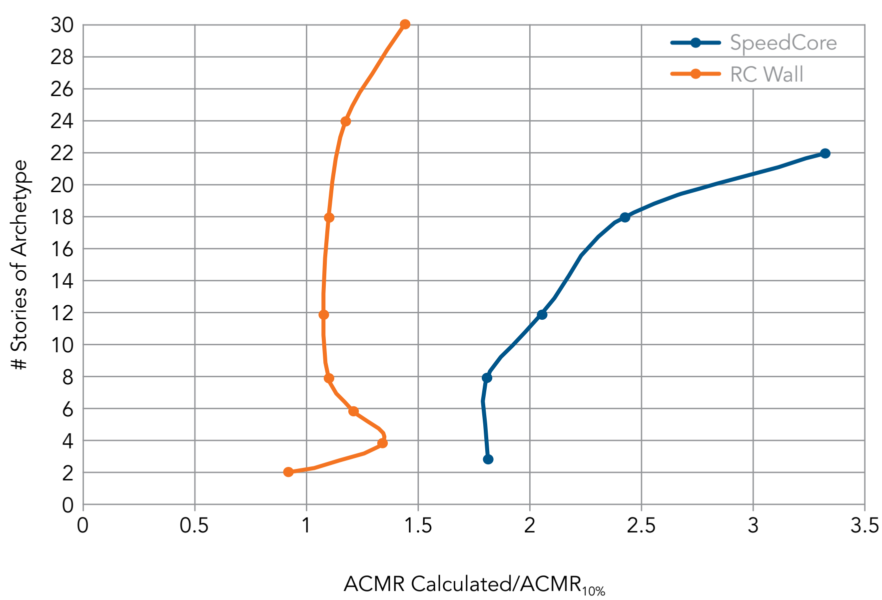
The RC walls P695 study examined a total of 41 two-story, four-story, six-story, eight-story, 12-story, 18-story, 24-story and 30-story archetypes, each considering varying types of coupling beams and reinforcement ratios. Researchers designed the archetypes using an *R* value of 8 and C_d value of 5.5 and calculated ACMRs for all archetypes using the P695 procedure.

Table 2. SpeedCore Archetypes ACMR Values

Archetype	ACMR Calculated (lowest)	$ACMR_{10\%}$	ACMR Calculated (lowest) / $ACMR_{10\%}$
Three-Story	3.55	1.96	1.81
Eight-Story	3.54	1.96	1.81
12-Story	4.02	1.96	2.05
18-Story	4.75	1.96	2.42
22-Story	6.5	1.96	3.32

Table 3. RC Wall Archetypes ACMR Values

Archetype	ACMR Calculated (lowest)	$ACMR_{10\%}$	ACMR Calculated (lowest) / $ACMR_{10\%}$
Two-Story	1.80	1.96	0.92
Four-Story	2.63	1.96	1.34
Six-Story	2.37	1.96	1.21
Eight-Story	2.16	1.96	1.10
12-Story	2.11	1.96	1.08
18-Story	2.16	1.96	1.10
24-Story	2.3	1.96	1.17
30-Story	2.83	1.96	1.44



Comparison Between Systems

In comparing the two tables, you may note that all SpeedCore archetypes had an ACMR greatly above the ACMR at 10% likelihood of exceedance. The RC wall archetypes also had ACMRs generally above the ACMR at 10% likelihood of exceedance, exceptung the two-story archetypes. However, the ratios of ACMR Calculated/$ACMR_{10\%}$ for SpeedCore far exceed those for RC wall systems.

Fig. 2. Comparison of ACMR Calculated/ ACMR10% for SpeedCore and RC Walls

Conclusions and Discussion

What exactly does it mean to have noticeably higher ACMR values from a P695 analysis?

Well, one thing to remember is that the current maximum *R* factor is 8, based on the previous performance of existing lateral force-resisting systems. It is conceivable that the calculated *R* values for new systems like SpeedCore could exceed the current maximum. To push the *R* value above 8, say to 10 or even 12, would require further analytical verification of the system, and then the results would need to convince the governing code bodies (BSSC-PUC) that the change is warranted. It is likely that the BSSC-PUC would be reluctant to change the value without ample testing evidence, analytical modeling, and extensive demonstrations that the change is warranted.

Pursuing a higher *R* value would also require supportive research and some education of existing PUC members and the engineering community as a whole on the design philosophy for these types of systems. RC wall systems have been around much longer, so the structural engineering community as a whole may not understand SpeedCore systems as well.

Much of the community thinks SpeedCore and RC wall systems are identical in performance and that the only difference between them is one uses more steel then the other, but this is incorrect.

RC wall systems typically exhibit flexural compression failure at the base of each wall pier. SpeedCore's capacity-based design approach, however, forces a sequence of hinging at coupling beams first, and then at a base of the wall. This key difference explains SpeedCore's appreciable increases in collapse margin ratios relative to the RC wall system.