MEMBER AND HYSTERESIS MODELS FOR SUBSTRUCTURE-BASED HYBRID EARTHQUAKE RESPONSE ANLYSIS

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Introduction Frames should be designed in such a way that any inelastic behavior during a severe earthquake should desirably commence at the critical sections of beams. The beams should, therefore, be able to sustain large deformation as the columns continue to take in more loads. However, the rotational ductility ratio required has not yet been clearly established in design codes. Tests of isolated beam-specimens have used a wide variety of arbitrarily-defined displacement loading histories in the range of 2-10% beam shear span. In a recent study, Sattary-Javid and Wight [1987] have shown that there is no unique relationship between the lateral frame displacement and the displacement beam members, and that applied displacement histories on test specimens should reflect the position of the beam in the frame. Under a substructure-based on-line hybrid experimental system, displacements imposed on a specimen are computed by a step-by-step nonlinear analysis.

Member and Hysteresis Models One-component member model is used in this study for ease of computation and demonstration. Point-hinges at member ends are used to simulate inelastic behavior of beam members. Since the point of contraflexure will always be located at midspan of each beam member, the two nonlinear rotational springs are identically specified.

$$\begin{Bmatrix}\Delta m_a \\ \Delta m_b\end{Bmatrix} = \frac{K}{(\eta^{-1}+2)(3\eta^{-1}+2)} \begin{bmatrix} 4+3\eta^{-1} & 2 \\ 2 & 4+3\eta^{-1}\end{bmatrix} \begin{Bmatrix}\Delta\theta_a \\ \Delta\theta_b\end{Bmatrix}$$

In the above, rotational springs are infinitely stiff, i.e., $\eta\rightarrow\infty$, when member behavior is elastic. Point-hinges can be characterized by any suitably realistic hysteretic model. In this study, Takeda model is chosen.

Frame models A one-bay three-story frame configuration of 7m bay and 3.5m story height is used. Five frame models are investigated under various design considerations. Frame model FM-a is designed to satisfy the ATC-3 drift limitation of 1.5%. For model FM-b, members are of the same capacities as in FM-a, except that finite-length rigid joints are not considered. For model FM-c, a smaller section is provided in the lowermost beam, otherwise FM-c is same as FM-b. Beams in model FM-d are designed to sustain rotational ductility in the order of 7. All of these four frame models are subjected to the NS-component of the 1940 El Centro earthquake. Lastly, model FM-e frame with same member design as in model FM-a is subjected to an earthquake of twice the specified intensity.

Results Interstory story drifts are expressed in percentages of story height, while displacement of an analogous cantilever beam is expressed in percentages of shear span. Also shown are some displacement histories generated on-line during tests, though analytically in this numerical study.

FM-a

INTERSTORY	MAX. INTERDRIFT		BEAM	'TIP' DISPLACE.	
3rd & 2nd	+1.5%	-1.5%	7	+0.5%	-0.5%
2nd & 1st	+1.5%	-1.3%	8	+0.6%	-0.5%
1st & 0th	+1.2%	-1.1%	9	+0.7%	-0.7%

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FM-b

INTERSTORY	MAX. INTERDRIFT		BEAM	'TIP'DISPLACE.	
3rd & 2nd	+3.5%	-3.5%	7	+0.6%	-0.5%
2nd & 1st	+3.7%	-3.6%	8	+0.7%	-0.7%
1st & 0th	+2.3%	-2.3%	9	+0.9%	-0.8%

FM-c

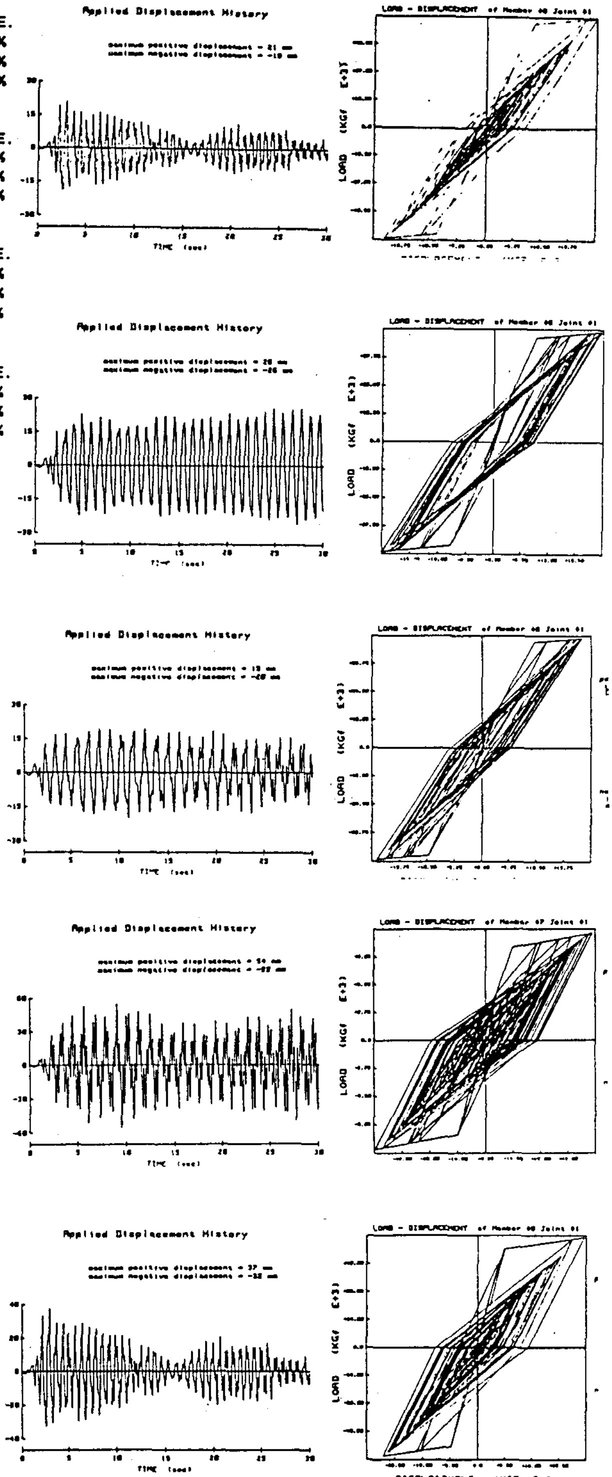
INTERSTORY	MAX. INTERDRIFT		BEAM	'TIP'DISPLACE.	
3rd & 2nd	+2.8%	-2.6%	7	+0.5%	-0.5%
2nd & 1st	+3.4%	-3.3%	8	+0.5%	-0.5%
1st & 0th	+2.5%	-2.5%	9	+2.5%	-2.5%

FM-d

INTERSTORY	MAX. INTERDRIFT		BEAM	'TIP'DISPLACE.	
3rd & 2nd	+3.3%	-3.5%	7	+1.5%	-1.5%
2nd & 1st	+3.5%	-3.3%	8	+2.7%	-2.8%
1st & 0th	+2.4%	-2.3%	9	+2.9%	-2.9%

FM-e

INTERSTORY	MAX. INTERDRIFT		BEAM	'TIP'DISPLACE.	
3rd & 2nd	+3.1%	-2.9%	7	+0.9%	-0.9%
2nd & 1st	+2.9%	-2.6%	8	+1.1%	-0.9%
1st & 0th	+2.4%	-2.1%	9	+1.3%	-1.2%



Discussions Model FM-a drifted within the limit of 1.5% as stipulated. In additions, beams at the different levels in FM-a were all designed to sustain ductility in the order of 2-3. Although FM-b drifted twice as much as FM-a, deformations in beams are of comparable range. In FM-c, however, the 'weaker' lowermost beam sustained deformations thrice more than the corresponding beam in FM-b, although the drifts in FM-b and FM-c are comparable. Even after undergoing large deformations, the beams had maintained integrity by carrying slightly less loads as the columns pick up more. A specimen tested under a constant-displacement history of over 2% shear span would have failed after a few cycles [Hwang and Scribner, 1984].

Concluding Remarks By appropriate member modeling incorporating suitably good hysteresis models, substructure-based hybrid earthquake response analysis procedure can be used to investigate ductility requirement of beams under realistic earthquake loadings.

References Hwang and Scribner [1984], 8WCEE; Sattary-Javid and Wight [1987], ASCE.