Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

8-1-13

A MODAL COMBINATION FOR DYNAMIC ANALYSIS OF REINFORCED CONCRETE FRAMES

Javier R. PIQUE[1] and Alberto ECHARRY[2]

[1]Professor, Faculty of Civil Engineering. National University. of Engineering (UNI). Researcher, Peru-Japan Center for Earthquake Research and Disaster Mitigation (CISMID), UNI. Lima, PERU
[2]Assistant Professor, Faculty of Civil Engineering. UNI. Lima, PERU

SUMMARY

A modal combination for elastic dynamic analyses of reinforced concrete frames currently built in Peru is presented here. This could be applicable to buildings subjected to subduction origin earthquakes with high frequency content. A number of predesign frames with and without shearwalls was analyzed with time history and spectral analysis subjected to 5 Peruvian records. A modal combination called "Weighted Average, WAn" was found in better agreement than currently used SRSSn and average of sum of absolute values and SRSS.

INTRODUCTION

In dynamic analysis one has the alternative of time-history or modal spectral analysis. The last one is usually preferred because of cost. Uncertainty exist as to the agreement with "exact" or time-history response. Peruvian Seismic Regulations establish (Ref 1) as modal combination the average (AVn) of the sum of absolute maximum responses (SABSn) and of the square root of the sum of the squares (SRSSn) of the first "n" modal responses. On the other hand, Peruvian earthquakes are originated in the subduction zone between the Nazca and South American Plates relatively close and parallel to the Andean ridge. This records have unusually high frequency contents implying that this combination, adopted from areas subjected to different earthquakes may not be applicable. In fact it has been found to be too conservative and the old one used SRSSn, to be unsafe.

Records 5 earthquake records were used, all registered in Lima. October 17, 1966; May 31, 1970; January 5, October 3, and November 9, 1974. (Ref 2). Response spectra for these records are presented in Fig. 1. These were obtained by direct integration of the record. No normalizing was done in order to include this variable into account.

FRAMES STUDIED

A total of 8 frames having 4, 8, 12 and 15 stories high were designed as to represent actual buildings being built in Peru. 4 had shear walls and 4 not, although all had similar geometry (Fig. 2) . Spans and heights were selected as to correspond to the most commonly used. Sizes were proportion to support usual concrete joist slabs with office loads.

THEORETICAL MODELS

A number of previous studies were done using shear and bending beams. These were very useful in studying different modal combinations and furnished a first insight in proposing the weighted average suggested here. It was also possible to observe a close agreement between the periods of a shear beam and those of the ductile frames and between the average of periods of the shear and bending beams and those of rigid frames (frames with shear walls) (Ref 6).

DYNAMIC ANALYSIS

All frames were analyzed using time history and modal spectral analyses. (Ref 4,5) with each of the five records. Spectra were computed from the records themselves. Time history was performed integrating directly the modal equations of motion. This was repeated using different number of modes "n" as to evaluate the minimum required to define the "exact response", "THn".The linear acceleration method of integration was used. Response spectrum analyses were done using spectral ordinates computed from the records themselves.

Proposals for Modal Combination Based on previous studies (Ref 3) and other trials (Ref 6) with different number of modes and modal combinations, searching for the best agreement with time history response, it was established that SRSSn (Square root of the sum of the squares of the first n modes) is a lower limit of the response and the arithmetic average of SRSSn and ABSn (sum of the absolute values) overestimates them. This was repeated for global (floor displacement and shears) and local effects (shear, bending moment and axial forces). A new "weighted average of SABS and SRSS" (WAn) was tried, in this case

0.25 SABS + 0.75 SRSS.

TIME HISTORY VERSUS SPECTRAL ANALYSIS

A number of plots is presented showing performance of the proposed combination and SRSS by comparison. Ordinate axis is the ratio of THn/WAn or THn/SRSSn. A value of 1 is the target. Higher values are "negative errors" or underestimations. Lower values the contrary. Horizontal axis presents ABSn/(modal combination) and illustrates the importance of higher modes in the response. Digits in the plots indicate number of repetitions at the same point.

Record influence on the reponse It was observed that responses on story shears and local effects were influenced by the record. Floor displacements, on the contrary were not much affected. However, in general, it can be said the scatter of the response is similar to all records and the same in the average.

Floor Displacements a) Ductile Frames (no shear walls).- Variation with number of floors is insignificant. Only 3 modes are necessary for best results with both combinations, SRSS3 and WA3. (Fig. 3,4) In all cases WA gave good results, reducing maximum negative errors of SRSS3 between 64% to 90%.

b) Frames with shear walls.- Response is variable with number of floors. However, WAn showed negative errors similar to those with ductile frames and lower than SRSS3. This indicates WAn is a more stable combination. Also 3 modes were necessary in this case for best results with both combinations. Results show higher underestimations than for flexible frames, specially with SRSS3.

Global Story Shears a) Ductile Frames.- WAn gives good results if sufficient number of modes is included as a function of the number of floors. In 12 and 15 story frames including 2 or 3 more modes reduced maximum errors (-28% and -21%) by 54% and 76%, whereas same modes increment with SRSS only reduced errors by 4% for the 12 story frame and 24% for the 15 story one. Maxima errors increased with the number of floors, up to 12 stories, except for 15 stories, depending on the combination used (Fig. 5).

b) Frames with shear walls.- In this case the combination used is more important than the number of modes considered in terms of floor number. (Fig. 6,7). For the 12 and 15 story frames WA3 and WA5 gave similar negative maximum errors. Same for SRSS3 and SRSS5. However with WAn results were better.

Local Effects (Shears, bending moments and axial forces) a) Ductile frames.- WAn gives good estimates of the response provided an adequate number of modes is considered, specially for buildings taller than 8 stories (Fig. 8,9). SRSSn always underestimates the response. Maximum negative errors do not decrease considering more than 3 modes (Fig. 10), the only exception being the 15 story frame with a reduction from -29% to -22% with 6 modes. WAn responses may be considered deficient for more than 8 stories. However they improve including 2 more modes for 12 stories and 3 modes for 15 stories.

b) Frames with shear walls.- WAn responses do not improve much when more than 3 modes are considered. SRSSn responses do not improve either with more than 3 modes and values are underestimated for frames taller than 8 floors. For 12 and 15 stories frames WAn underestimates the response up to 22%, being this the only case where this occurs with this combination (Fig. 12,13).

CONCLUSIONS

- Shear beam provides a rapid estimation for periods of flexible frames.

- Bending beam periods are a lower limit and shear beam periods an upper one for stiff frames. The average of both provides a good estimate.

- The Weighted Average combination "WAn" is safer than SRSSn and gives a good estimate for global and local responses, specially of flexible frames provided an adequate number of modes is considered. Average response falls on target and low and high estimates are within reasonable limits. WAn gives better results for taller buildings. The SRSS combination underestimates the results regardless the number of modes involved. For stiff frames is recommended to modify WAn according to recommendation No. 3 below.

- WAn will always give lower responses than AVn and higher than SRSSn meaning neither conservative or inadequate responses in frames taller than 8 floors.

RECOMMENDATIONS

The following modal combinations are suggested:

1) For displacements, any number of floors: 0.25 SABS + 0.75 SRSS with 3 modes.

2) For global shear forces and local shears, bending moments and axial forces, use 0.25 SABS + 0.75 SRSS for flexible structures (no shear walls), with 3,4,5 and 6 modes for buildings, 4,8,12 and 15 stories high. In stiff structures (with shear walls), use 3 modes for up to 8 floors and 4 modes for

taller frames. In both cases SRSS is not recommended because 70% of responses are underestimated.

3) Best results for stiff frames are obtained with 0.30 SABS + 0.70 SRSS using 4 or 5 modes specially for more than 8 stories.

4) Arithmetic average , AVn may be a valid alternative for strategic structures where a 100% certainty of seismic force estimation is needed. For normal building frames is too conservative.

REFERENCIAS

(1) O.I.N., Ministry of Housing. "Normas Peruanas de Diseño Sismo Resistente". Lima. Perú. 1977.

(2) BRADY A.G., PEREZ, V., "Strong Motion Earthquake Accelerograph: Digitization and Analysis. Records from Lima, Perú: 1951 to 1974. Open File Report 77-587. U.S. Geological Survey. Menlo Park, California. 1977

(3) COLL CALDERON J. D., "Análisis Dinámico del Pórtico Plano: Tiempo Historia vs. Espectro". Thesis submitted in fulfillment of the requirements for the degree of Civil Engineer. Faculty of Civil Engineering. National University of Engineering Lima. Perú. 1979.

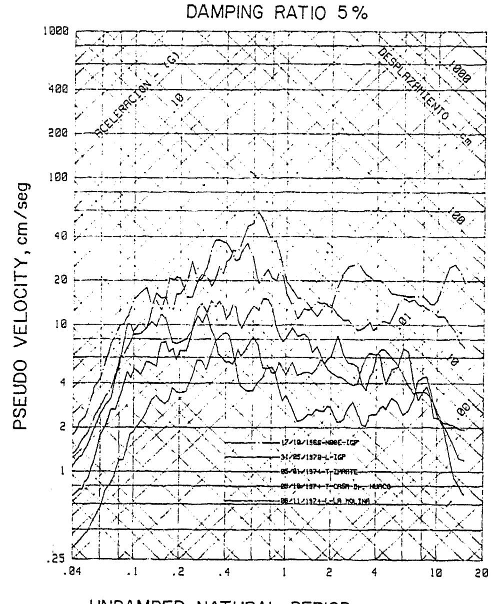
(4) BIGGS. J.M., Introduction to Structural Dynamics. McGraw-Hill & Co. New York. 1964.

(5) ROESSET J.M., "Class Notes on Numerical Methods for Structural Dynamics". M.I.T., Cambridge, Mass. 1974.

(6) ECHARRY A., "Propuesta de Combinación Modal para el Análisis Dinámico Espectral de Edificios". Thesis submitted in fulfillment of the requirements for the degree of Civil Engineer. Faculty of Civil Engineering. National University of Engineering. Lima. Perú. 1987.

Fig. 1 PERUVIAN RESPONSE SPECTRA

DAMPING RATIO 5%



UNI-FIC

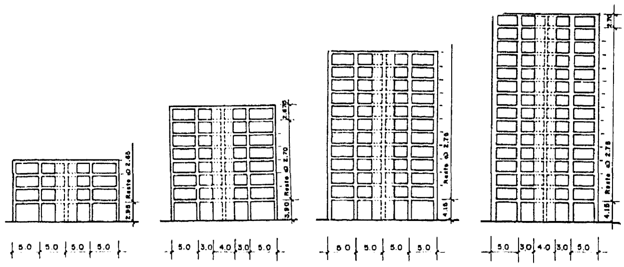


Fig. 2 BUILDING FRAMES ANALYZED: 4, 8, 12, and 15 STORIES WITH AND WITHOUT SHEAR WALLS

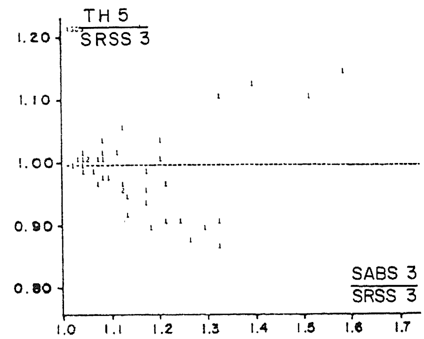


Fig. 3 FLOOR DISPLACEMENTS. SRSS 3. 8 STORY FRAME

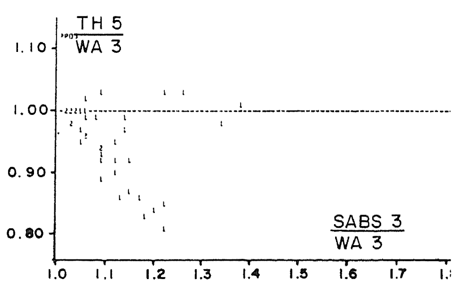


Fig. 4 FLOOR DISPLACEMENTS. WA 3. 8 STORY FRAME

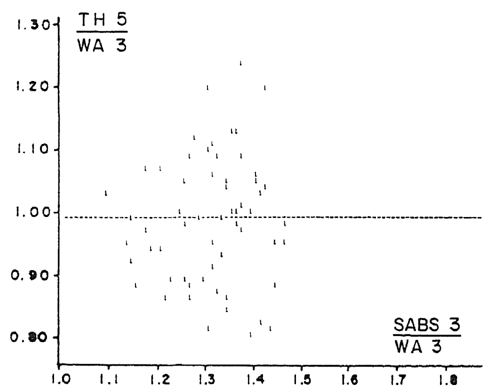


Fig. 5 STORY SHEARS. WA 3. 12 STORY FRAME

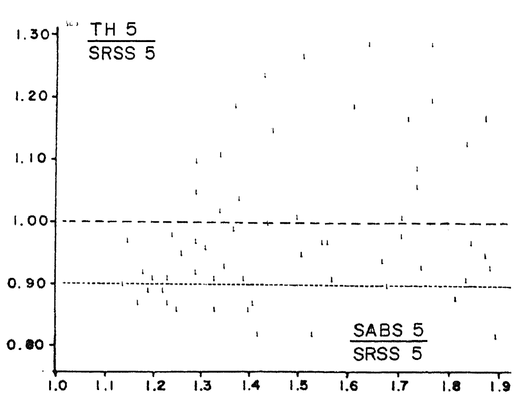


Fig. 6 STORY SHEARS. SRSS 5. 12 STORY FRAME WITH SHEAR WALLS

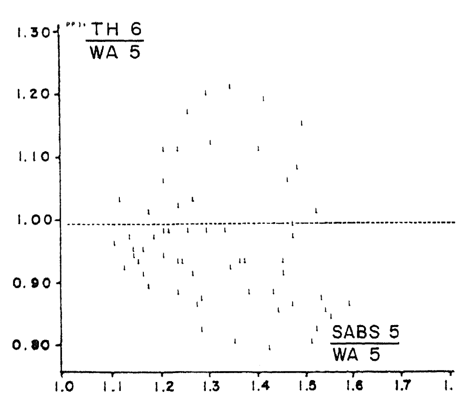


Fig. 7 STORY SHEARS. WA 5. 12 STORY FRAME WITH SHEAR WALLS

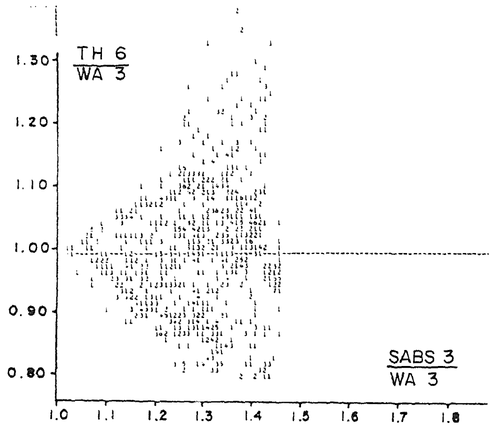


Fig. 8 LOCAL EFFECTS. WA 3. 12 STORY FRAME

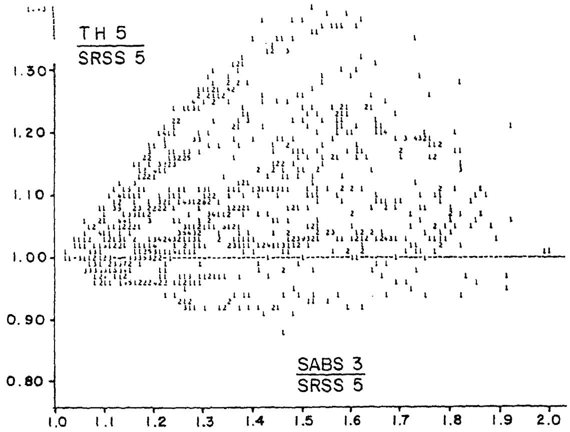


Fig. 11 LOCAL EFFECTS. SRSS 5.
12 STORY FRAME WITH SHEAR WALLS

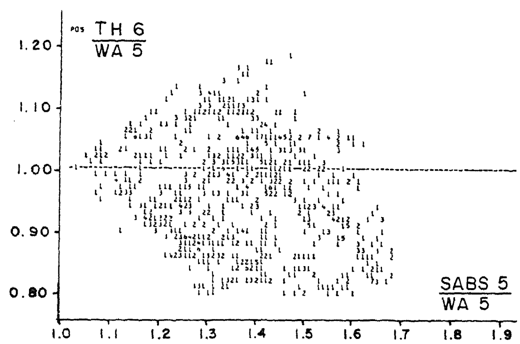


Fig. 9 LOCAL EFFECTS. WA 5 . 12 STORY FRAME

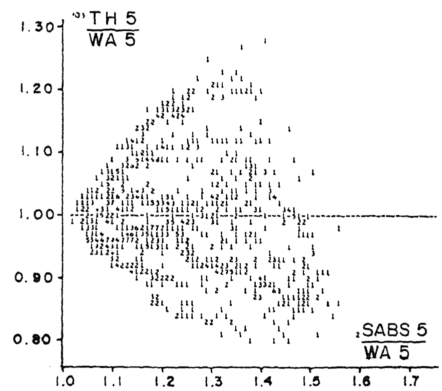


Fig. 12 LOCAL EFFECTS. WA 5.
12 STORY FRAME WITH SHEAR WALLS

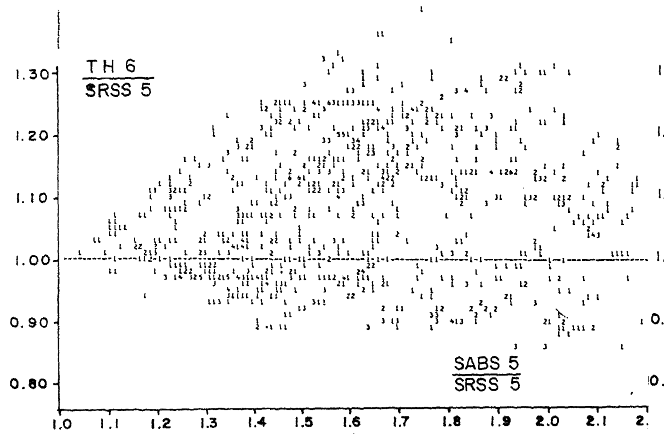


Fig. 10 LOCAL EFFECTS. SRSS 5. 12 STORY FRAME

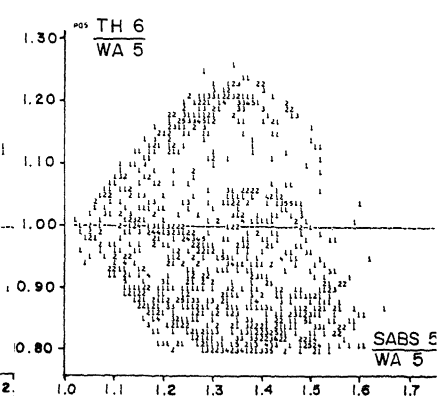


Fig. 13 LOCAL EFFECTS. WA 5.
15 STORY FRAME WITH SHEAR WALLS