# *Termination of the Response Spectrum Method - RSM*
### *Ed Wilson – July 13, 2015*

## ***History of the RSM for Seismic Analysis***

Ray Clough and I regret we created the approximate response spectrum method for seismic analysis of structures in 1962. At that time many members of the profession were using the sum of the absolute values of the modal values to estimate the maximum member forces. Ray suggested we use the SRSS method to combine the modal values. However, I am the one who put the approximate method in many dynamic analysis programs which allowed engineers to produce meaningless positive numbers of little or no value. In early 1980 Arman Der Kiureghian and I replaced the SRSS method with the CQC method. This new approach had been used in Random Vibration of mechanical engineering equipment to produce a ***maximum peak value*** for one force or one displacement at an unspecified point in time. Therefore, the use of the method in earthquake engineering, where the duration of vibrations are a few minutes and not several hours, required the introduction of additional approximations. After working with the RSM for over 50 years, I recommend it not be used for seismic analysis.

## ***The equation which that should have terminated the RSM of analysis***

By 1990 researchers and many members of the profession had created the Demand/Capacity Ratio for beams. In order to satisfy various building codes specify that all one-dimensional **compression** members within a structure satisfy the following Demand/Capacity Ratio at all points in time:

$$R(t) = \frac{|P(t)|}{f_c P_{cr}} \pm \frac{M_2(t) C_2}{f_b M_{c2}\left(1 - \frac{|P(t)|}{P_{e2}}\right)} \pm \frac{M_3(t) C_3}{f_b M_{c3}\left(1 - \frac{|P(t)|}{P_{e3}}\right)} \leq 1.0$$

Where the forces acting on the frame element cross-section at time "t" are $P(t)$, $M_2(t)$ and $M_3(t)$ (including the static forces prior to the application of the dynamic loads). The empirical constants are code and material dependent and are normally defined as

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| $f_c$ and $f_b$ | = | Resistance factors |
| $C_2$ and $C_3$ | = | Moment reduction factors |
| $M_{c2}$ and $M_{c3}$ | = | Moment capacity |
| $P_{cr}$ | = | Axial load Capacity |
| $P_{e2}$ and $P_{e3}$ | = | Euler bucking load capacity about the 2 and 3 axis with effective length approximated. |

For each **time-history seismic analysis**, $P(t), M_2(t)$ and $M_3(t)$ at every cross-section of all members can be easily calculated as a function of time. Therefore, the maximum Demand/Capacity Ratio, $\boldsymbol{R(t)}$ for all load conditions, can be accurately calculated and identified by any modern computer analysis design program in a fraction of a second. All of the CSI series of programs have this capability built into their interactive post-processing programs. For each **response spectrum analysis,** however, the value of $P(t), M_2(t)$ and $M_3(t)$ cannot be calculated accurately since only positive values of $\boldsymbol{P}, \boldsymbol{M}_2$ *and* $\boldsymbol{M}_3$ are produced. These are peak maximum values have a very low probability of occurring at the same time. Therefore, the Demand/Capacity Ratios are always significantly greater than those produced by a time-history analysis.

The author, acting as a consultant on the retrofit of the San Mateo Bridge after the Loma Prieta Earthquake, has had significant experience with the problem of calculating Demand/Capacity Ratios using the response spectra method. The seismologists and geotechnical engineers created two different sets of three-dimensional ground motions. They generated both near and far field motions from both the Hayward and San Adreas faults. Then, they averaged the various ground motions and produced three-dimensional design spectra to be used to design the retrofit of the Bridge.

The structural engineering group that tried to use the design spectra for the analysis and retrofit of the bridge found that a large number of members in the structure required retrofit. After a careful study of the maximum peak values of the member forces (especially the large peak axial forces), it was decided to run new time-history analyses using the basic time-history records that were used to create the design spectra. After running all the time-history records, the maximum **Demand/Capacity Ratios as a function of time were reduced by approximately a factor of three compared to the design spectra results**.

The only excuse I can offer, for my part in the development of the RSM of analysis, is **in 1962 we only had three different real earthquake motions**; now, we have several thousand real earthquake recordings. Therefore, it is now the responsibility of your generation to advance the profession to the next level and eliminate the uses of the RSM of analysis. Also, the cost of computations has been reduced by over 100 million times during the last 50 years.

## <u>My Recommendation</u>

After conducting dynamic analyses of several hundred different types of structures, subjected to earthquake displacements, I have always spent the majority of my time identifying the structural elements and preparing the computer model. After a realistic computer model is created I would "play" with the model. By "play" I mean to physically understand the dynamic behavior of the structure.

First; look at the animated plots of the mode shapes and examine the direction of the base shears and see if the lower modes produce significant torsion at the base. If this exists, I would suggest the structure be redesigned to minimize torsion in the lower modes. This is why design and analysis should not be conducted by different people. The direction of the base shear of the first mode, with the longest period of the structure, defines the principle direction. In general, the base shear of the second mode should be approximate 90 degrees to the first mode. This defines the two directions in which the three-dimensional earthquake displacements should be applied, not in the X-Y or North-South directions.

Second; I would take several different earthquake motions, of different magnitude and durations, to check what members would be first to yield. Also, I would check which members are over designed. Then I would redesign the structure and "play" with different designs.

Third, CSI has recently added the ability to generate "time histories" from user specified spectra. Therefore, it now possible for every structural engineer to conduct linear time-history response analysis complex structures which satisfies all building code requirements.

Seriously, it is now possible to play with any complex structure in a few days of fun work. SAP 2000 or ETABS are great programs for the designer to conduct their own research on the behavior of many different types of buildings systems.

Why would anyone want to design a 3D frame element for forces that are not in equilibrium?

***Do not be called a Neanderthal man.***

***The RSM must be terminated before Engineers will use Performance Based Design, PBD.***

***After they perform time history analysis Engineers will realize non-linear analysis is easy***

***Using the Fast Nonlinear Analysis, FNA, method.***

***This will allow many structures to be Reparable after a Large Earthquake.***

The FNA method was developed and verified by CSI and myself during the last 25 years. It allows all existing SAP2000, ETABS and CSI Bridge users to conduct PBD by replacing a few linear elements with nonlinear elements. Therefore, the user is not required to create a new model or learn to use a new computer program. Based on the conservation of energy principal the program automatically selects the size of the time step as a function of time. Therefore, the method is very robust and rarely fails to obtain a solution.

During the past 20 years, the FNA method has demonstrated excellent agreement with the results from dynamic laboratory tests of nonlinear models. It has been very satisfying to me to have structural engineers, all over the world, are using the FNA method to design real PBD structures which satisfy the fundamental equations of mechanics at all points in time.

## CASE CLOSED

*The use of the Response Spectrum Method in Earthquake Engineering must be terminated.*

*It is not a dynamic analysis method – The results are not a function of time.*

*If you have any questions do not hesitate to contact me at ed-wilson1@juno.com*