Modelling the damping effect for structures in reinforced concrete frames

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Abstract. In this paper we study the influence of the damping on the stress and displacements response for a reinforced concrete structure P + 4. In this sense, it was used a mesh consisting of two overlapping layers with common junctions. A concrete layer and a reinforcement layer Therefore, a numerical study was carried out by the help of an especially made program (a rewriting of the NONSAP PC program where a graphic postprocessing software was created). Finally, we obtained the structural response from the effect of the concrete degradation in the areas of the plastic joints. The paper presents our recommendations regarding the use of damping for reinforced concrete structures.

1. Viscous damping
Resistant damping forces, currently used in calculating the dynamic response of moving mechanical systems, correspond to the following models for the damping phenomenon:

- viscous damping (resistant force proportional with velocity) \( F_d = -c \cdot \dot{x} \)
- hysteretic structural damping (resistant force proportional with displacement but out of phase from it) with \( \pi/2 \), \( F_d = igkx \)
- colombian damping (dry friction-resistant force proportional to the normal surface reaction on which the displacement of a point occurs \( F_d = fN \text{ sgn} \, x \)

Each of these models, for damping forces, has a specific scope of application, so that substitution of one type of strong force through another can only be made in full knowledge of the phenomena that take place.

For frame structures we are interested in viscous damping, which, as it is well known, can be modeled by the Rayleigh model to model energy dissipation inside the structure. It is possible to estimate the rate of effective viscous damping from structural tests.

One of the methods is to apply a static displacement by applying a cable to the structure and then suddenly removing the cable load. Obviously we can measure the values of two subsequent successive amplitudes, through the known relationships, while obtaining the fraction of critical damping.
In elastic dynamic analysis it is very common to use a 5% damping. Always, this value is in many cases very little experienced or justified theoretically. In the Rayleigh viscous damping model [1], the damping matrix \([C]\) is calculated using multiplication constants for the mass matrix \([M]\) and for the stiffness matrix \([K]\):

\[
[C] = \alpha [M] + \beta [K]
\]  

(1)

The constants \(\alpha\) and \(\beta\) are calculated according to the fractions of the critical damping \(\xi\), corresponding to their own vibration mode “i”, and then \(\alpha\), \(\beta\) satisfy the relation (see in figure 1):

\[
\xi_i = \frac{\alpha}{2\omega_i} + \frac{\beta \omega_i}{2}
\]  

(2)

We will admit that the sum of constants \(\alpha\) and \(\beta\) is almost constant for a certain range of circular frequencies.

Using the fractions of critical damping and corresponding circular frequencies of two vibration modes, we determine the constants \(\alpha\) and \(\beta\) and solve the system of equations (2).

![Figure 1. The damping-circular frequency relationship.](image)

The problem of damping, and in particular the problem of structural damping, should be more broadly defined, both for materials with linear and non-linear behavior. In the case of structures in reinforced concrete frames, nonlinear behavior is well-known: the yielding of the reinforcement and the crushing of the concrete.

2. The level of damping in structures

The appreciation of the level of damping of structures in their different modes of oscillation still has a subjective character.

Although there are numerous papers on the values of the critical damping fraction in the different modes of oscillation, one cannot speak of a theoretical substantiation of the phenomenon. That is why the evaluation of the damping of a structure can only be done by considering as many of the parameters defining the phenomenon as possible (the shape of the structure, the nature of the materials used, the foundation ground, the excitation, etc.)

Taking into account the important contribution of the damping in determining the dynamic response of a structure, it is admitted that the damping effects are considered to come from a viscous damping (possibly a viscous damping equivalent to a structural damping) for which the critical damping fraction has the same values in all modes of oscillation.
3. Case study
The case study consists of a linear elastic time-history analysis of a P + 4. For the modeling of reinforced concrete (beams and pillars), two layers were used with joint displacements at the nodes. A concrete layer made of 8-nodes rectangular elements and a reinforced layer made of "Truss" elements. The reinforcement areas obtained from the sizing were used, using static seismic forces equivalent to seismic grouping [3], [6].

The accelerogram used is one recorded and scaled to 0.16g and the duration of the calculation step is 0.02s and the accelerogram duration is 16s (figure 2).

![Figure 2. Recorded accelerogram (1977) in m/s², duration 16s.](image)

For use, the variation of nodal force applied over time (figure 2), the graph in the figure was resolved to 0.2g and amplified with the nodal masses.

One of the major advantages of the Direct Numerical Integration Method consists in its application without difficulty to the dynamic analysis of the structures allowing the introduction of the damping in analysis.

Another advantage of integration over time is that the mathematical equation of motion is the approach method to approximate the real phenomenon.

It is to be noted that most seismic design rules do not recognize the variation in damping depending on the type of material and the level of effort in the structure, specifying in all cases a fraction of the critical damping of 5%.

In order to obtain the coefficients $\alpha$ and $\beta$ a modal analysis was performed, and the values of the own vibration modes obtained are presented in Table 1.

| Vibration mode | $\omega_i$ [rad/s] | $T_i$ [s] |
|----------------|-------------------|----------|
| 1              | 15.97             | 0.39     |
| 2              | 51.94             | 0.12     |
| 3              | 89.91             | 0.06     |
Using two successive frequencies and the relationship \( \alpha + \beta \cdot \omega^2 = 2 \cdot \omega \cdot \xi \), and solving the system [2], the proportional constants of the damping matrix are obtained, according to Table 2.

| Damping | \( \alpha \)  | \( \beta \)  |
|---------|----------------|----------------|
| 3%      | 0.72           | 8.86E-4        |
| 5%      | 1.21           | 1.45E-3        |
| 7%      | 1.7            | 9.06E-3        |

Response comparisons between the three critical damping fractions are shown in Table 3.

| Damping | Dymax (at the top) | Maximum compression effort at the ends of the beams \( daN / cm^2 \) | Maximum compression effort at the base of the pillars \( daN / cm^2 \) |
|---------|--------------------|-------------------------------------------------|-------------------------------------------------|
| without damping | 0.602E-1 | 382.2 | 355.4 |
| 3% | 0.259E-1 | 172.9 | 162.6 |
| 5% | 0.21E-1 | 146.2 | 138.8 |
| 7% | 0.188E-1 | 131.3 | 125.8 |

**Figure 3.** Deformed shape, calculation step 544, Dymax = 0.21E-1, 5% damping.

Whenever a material, element, or structure is required by cyclic loads, the cyclic loading-deformation curve (strength-strain) is not a uniquely defined function but forms a hysteresis curve [5].

The structural-hysteretical damping, in the present case, can occur due to phenomena such as: the non-linear behavior of the concrete, the yielding of the reinforcement. It is well known that plastic entry of the reinforcement and cracking of the concrete increase the structural damping.

The second part of the study introduces the effect of degradation of concrete in the areas of plastic joint formation. The maximum compressed stresses were used. A two-stage calculation was
performed: in the first stage efforts were made in elements, concrete and reinforcement (5% damping efforts); in the second stage the stiffness at the ends of the beams and at the base of the pillars was reduced.

The elastic modulus has been operated in areas where tensions have reached the limit, obviously in the sense of reducing it [4].

In this situation, the maximum displacement, shown in figure 3, increased from 0.021m to 0.037m.

4. Conclusion

Using a 5% or 7% damping in terms of the percentage of solutions means from the point of view of the displacement a difference around 10%. It is obvious that there are a number of factors that can falsify the response much more. One of them is the solution without damping. Other factors of influence of the response can be structural degradation during the seismic action and the influence of the foundation ground.

From the point of view of the structural degradation, on the chosen model, the displacements increase compared to the chosen reference value with 76%. A reference value was obtained in the case of 5% damping where maximum displacement is Dy = 0.021m.

In conclusion, it is obvious that in case of integration in time even if numerically we have to deal with a more elaborate solution, the impossibility of controlling all the terms involved can generate solutions errors.

Thus, the use of cover values for all the involved terms represents one of the most viable solutions.

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