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THE EFFECTS OF THE AXIAL LOAD VARIATION ON THE SEISMIC PERFORMANCE OF EXISTING RC BUILDINGS

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Abstract. *It is well known that the axial load plays an important role in the evaluation of the structural capacity of RC columns. In existing buildings this problem can be even more relevant than in new ones, since the material can easily present poor mechanical properties. The paper is aimed at investigating the role of the axial load variation on the seismic performance of RC columns, evaluated in terms of limit chord rotation and shear force, according to the EC8 provisions. The study is developed with reference to a case-study, which is a doubly symmetric 4-storey RC building. A dynamic (time history) analysis has been performed by adopting a fiber model for the cross section of the concrete members, to determine the structural response under the assumed seismic excitation. An ensemble of 7 ground motions, spectrum-compatible with the elastic spectrum provided by EC8 has been assumed as seismic input. The combined effects of the strength variability and axial load variation have been checked on the seismic performance of the columns of the 1st storey, which presented the higher levels of compression and axial load variation.*

1 INTRODUCTION

The axial load variation influences both the seismic demand and capacity of RC members [1-3], and therefore it is a relevant factor in the seismic performance evaluation [4-6]. Existing RC buildings are even more sensitive to the axial load variation than the new ones, since the material can easily present poor and uncertain mechanical properties. Moreover, the joints of existing buildings have been usually designed without specific confinement provisions, so resulting very sensitive to the reduction in ductility related to the increase of axial load [7-8].

Both the axial load variation and the concrete strength variability can largely affect the seismic performance of RC buildings. Their combined effect, therefore, can be even more important in such evaluation. This paper is aimed at investigating the combined effect of the concrete strength variability and the axial load variation on the seismic performance of RC structures. The study is carried out with reference to a case-study, i.e. a doubly symmetric 4-storey RC building [9-13], representing a typical example of pre-seismic code structure.

The seismic response of the case-study has been evaluated in terms of chord rotation and shear force of the RC members, by performing a time-history analysis with reference to two different limit states, i.e. the Damage Limitation (*DL*) and the Significant Damage (*SD*). The assumed seismic input is made of seven ground motions, whose elastic spectra fit very closely the elastic spectrum provided by Eurocode 8 (EC8) for the assumed soil type (B type).

The capacity of the structure has been found by accounting for the axial load in each considered member. On the basis of the concrete *mean* strength, two different alternative assumptions have been made to describe the members capacity. In the first one, the design value of compressive strength to be used in the analysis has been found by following the EC8 approach, i.e. by introducing a Confidence Factor (CF) based on the achieved knowledge level. In the second approach, instead, a hypothetical Gaussian distribution of the compressive strength has been assumed, considering the experimental *mean* value and different Coefficients of Variation (*CoV*). Three different *CoV* values, respectively equal to 15%, 30% and 45%, consistent with a large database of experimental values [14-15] have been assumed in the analysis. Each strength distribution has been discretized into seven percentile values, respectively equal to 5%, 10%, 20%, 50%, 80%, 90% and 95% [13, 16].

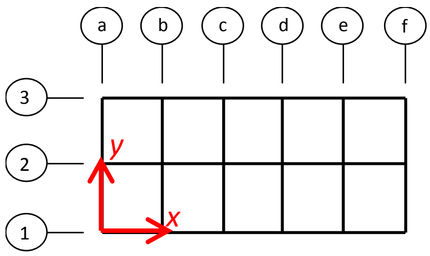
The seismic performance is expressed as the ratio between demand (D) and capacity (C) as a function of the variable axial load in each column. Due to the applied acceleration train, in fact, the axial load in each column ranges around an initial value, i.e. the axial load related to the gravity loads. The range of axial load experienced by each member is considered to define a range of capacity. By comparing the obtained results, the sensitivity of the seismic performance to the axial load variation has been checked, and the role played by the concrete strength assumptions has been discussed.

2. THE ANALYSIS

The sample structure [13], shown in Fig. 1, is a 4-story 3D reinforced concrete frame, symmetric along both *x* and y directions, with two 4.5 m long bays in the *y*-direction and 5 bays 3.5 m long in the *x*-direction, designed for vertical loads only. The concrete has been assumed to have a *mean* strength equal to 19.36 MPa, while for the reinforcement, the Italian FeB38k steel (yield stress over 375 MPa, ultimate stress over 430 MPa) has been assumed.

The *mean* values of concrete and steel strength have been assumed in the analysis for seismic response assessment, while the capacity of the case study has been evaluated considering two different assumptions for the concrete strength: the first one refers to the conventional EC8 approach, which requires to reduce the *mean* strength value by a *CF*, equal to 1.00, 1.20 or 1.35

respectively, depending on the knowledge level (KL3, KL2 and KL1) of the structure. The second one provides for a Gaussian representation of the probabilistic distribution of the concrete strength. In the Gaussian representation, the strength domain is defined [11-13] with reference to an extensive experimental campaign carried out by the Tuscan Regional Government [14-15]; a single *mean* strength, i.e. the EC8 value for *CF*=1.00 has been assumed, while three different *CoVs*, respectively equal to 15%, 30% and 45% have been considered. For each *CoV*, a sample of seven concrete strength values, corresponding to the percentiles of 5%, 10%, 20%, 50%, 80%, 90% and 95% has been assumed for the definition of columns capacity.



columns			beams		
dimensions	reinforcement		dimensions	reinforcement	
(cm)	long	transv.	(cm)	long	transv.
30x30	8 ϕ14	ϕ6/20 cm	30x50	3+3 ϕ12	ϕ8/20’

Figure 1 Plan configuration of the case-study and structural features of the RC members.

The seismic response of the case-study has been found by performing a nonlinear dynamic (time history) analysis through the computer program Seismostruct [17]. A fiber model has been adopted to describe the cross sections; the model by Mander [18] has been assumed for the core concrete, a three-linear model has been assumed for the unconfined concrete, and a bilinear model has been assumed for the reinforcement steel. The stiffness of floor slabs has been modelled by introducing a rigid diaphragm.

The seismic input has been defined by a set of 7 ground motions whose mean spectrum closely fits the EC8 elastic one (soil-type B). The records, described in Table 1, have been selected by the data-base Itaca [19], on the basis of a PGA equal to 0.25g, a nominal life of the structure of 50 years and a magnitude between 5.5 and 6.5.

Table 1. Ground motions data.

Name	Location	Date dd/mm/yyyy	PGA (g)	Duration (sec)
Irpinia	Sturno	23/11/1980	0.225	70.75
Irpinia	Calitri	23/11/1980	0.174	85.99
L’Aquila	Colle Grilli	06/04/2009	0.446	100.00
L’Aquila	Aquil Park Ing 1	06/04/2009	0.353	100.00
L’Aquila	Aquil Park Ing 2	06/04/2009	0.330	100.00
L’Aquila	Centro Valle 1	06/04/2009	0.545	100.00
L’Aquila	Centro Valle 2	06/04/2009	0.657	100.00

Two different limit states have been assumed in the present paper: the Damage Limitation (*DL*) and the Significant Damage (*SD*) limit states. According to EC8 provisions, the response parameter to be checked for the serviceability limit states is the chord rotation only, while both chord rotation and shear force must be checked for ultimate limit states. Therefore, in the present paper, a limit value corresponding to the yield chord rotation has been assumed for the *DL* limit state, while two limit values, based respectively on the ultimate chord rotation and ultimate shear force, have been assumed for the *SD* limit state. Both *DL* and *SD* limit values are strictly dependent on the axial load level in the RC members.

3 THE SEISMIC PERFORMANCE OF THE 1ST STOREY COLUMNS

3.1 The seismic demand

Fig. 2 shows the global response of the case study in terms of maximum drift, maximum shear force and maximum axial load variation (ΔN). All local results refer to the 1st storey columns, since they are the most affected by ΔN. The column drift, under the assumption of shear type behavior, can be assumed as coincident to the chord rotation, i.e. the assumed response quantity. Since the effects of ΔN are very sensitive to the initial amount of compression, it's important to check such variation for each single column.

Fig. 3 shows the maximum N (grey bars) and minimum N (white bars) experienced by each column of the case-study. The horizontal line in each figure represents the reference static axial load. Since, in each frame, the internal columns (column lines *b*, *c*, *d* and *e*) and the side ones (column lines *a* and *f*) respectively experience almost the same ΔN (see [12]), in Fig. 3 only the results of two columns for each frame have been shown, together to the static axial load of the two (side and internal) columns. It should be noted that, despite the building is symmetric along both main axes, ΔN is not the same in the two side frames (frames 1 and 3).

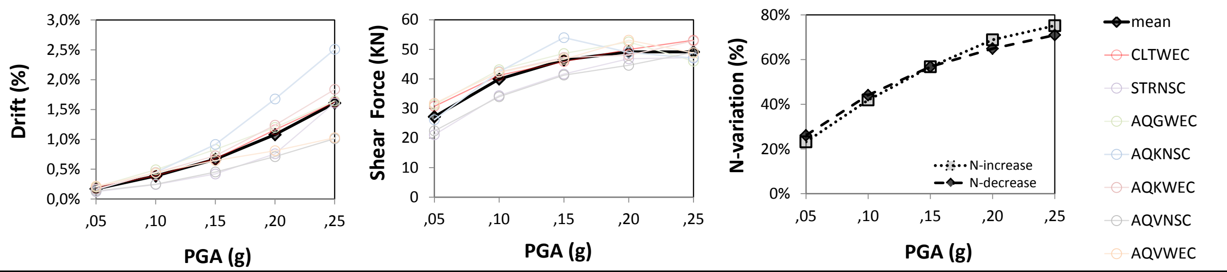


Figure 2. Seismic response of the case study.

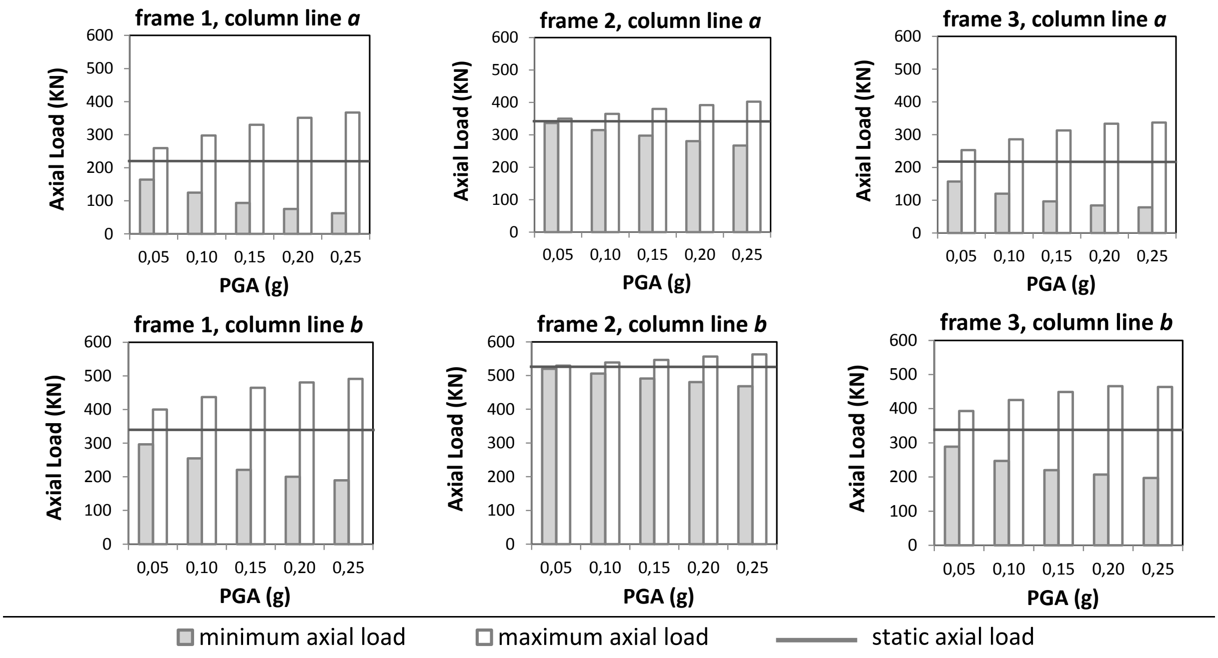


Figure 3. Axial load variation in the columns.

3.2 The seismic capacity

In this section, columns structural capacity is evaluated as a function of the axial load level, assuming both a variable concrete strength and the approach ofEC8 provisions. Figs 4 and 5 show, respectively, the sensitivity of the chord rotation and shear force capacities to the axial load variation for *DL* and *SD* limit states.

In each graph, the colored lines represent the domains related to the percentile values describing the assumed strength distribution related to the three different *CoV* values, while the black dashed ones represent the capacities provided by EC8. The domains have been interrupted in correspondence of the axial force capacity of the structural section. As can be noted, the range of capacities provided by EC8 is relevantly smaller than the one obtained when the probabilistic strength variability is considered, even for the lowest assumed *CoV* (*CoV* = 15%). For higher values of *CoV*, more likely to be found in existing buildings [9-10, 14], the difference between the two ranges is even more relevant.

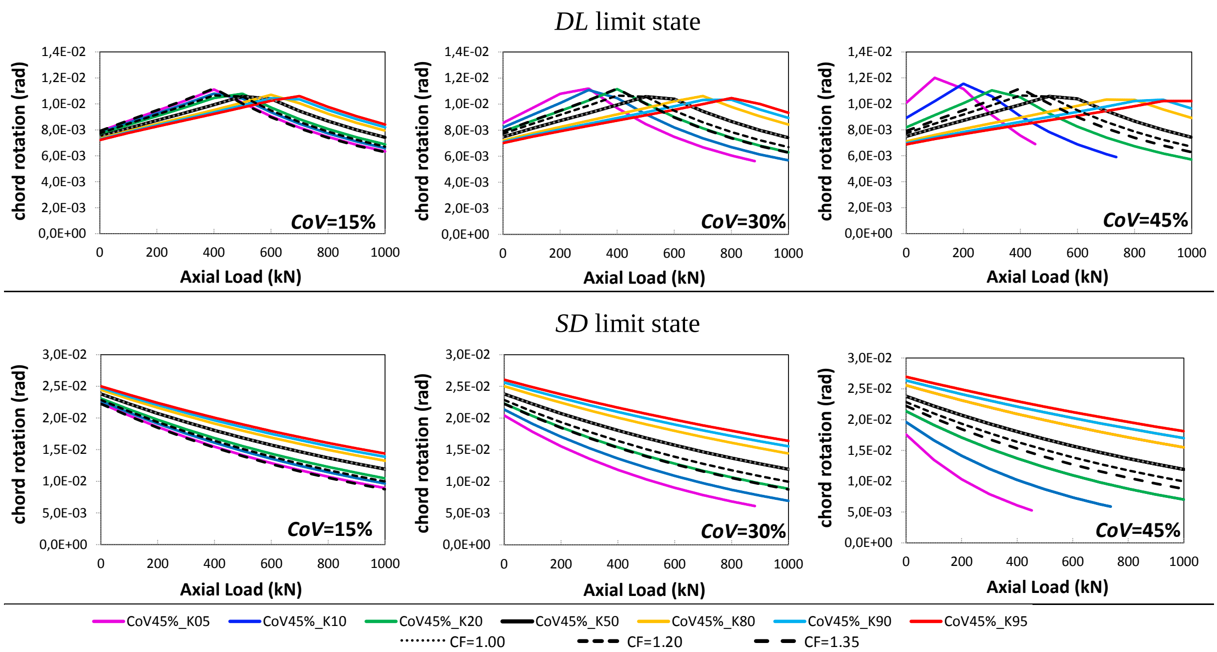


Figure 4. Sensitivity of the *DL* and *SD* chord rotation capacity of columns to the axial load variation.

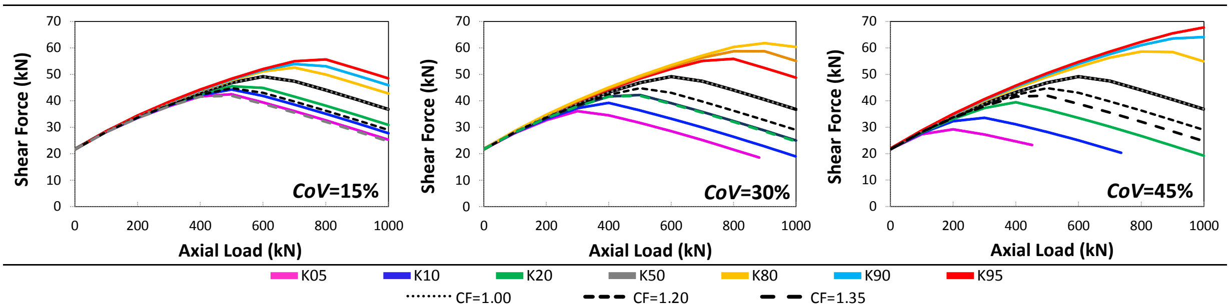


Figure 5. Sensitivity of the Shear Force capacity of columns to the axial load variation (*SD* limit state).

4 THE SEISMIC PERFORMANCE

The seismic performance has been quantified as the ratio between the demand (D) and the capacity (C) of each column at the first storey. The sensitivity of the seismic performance to the axial load variation has been investigated with reference to both *DL* and *SD* limit states.

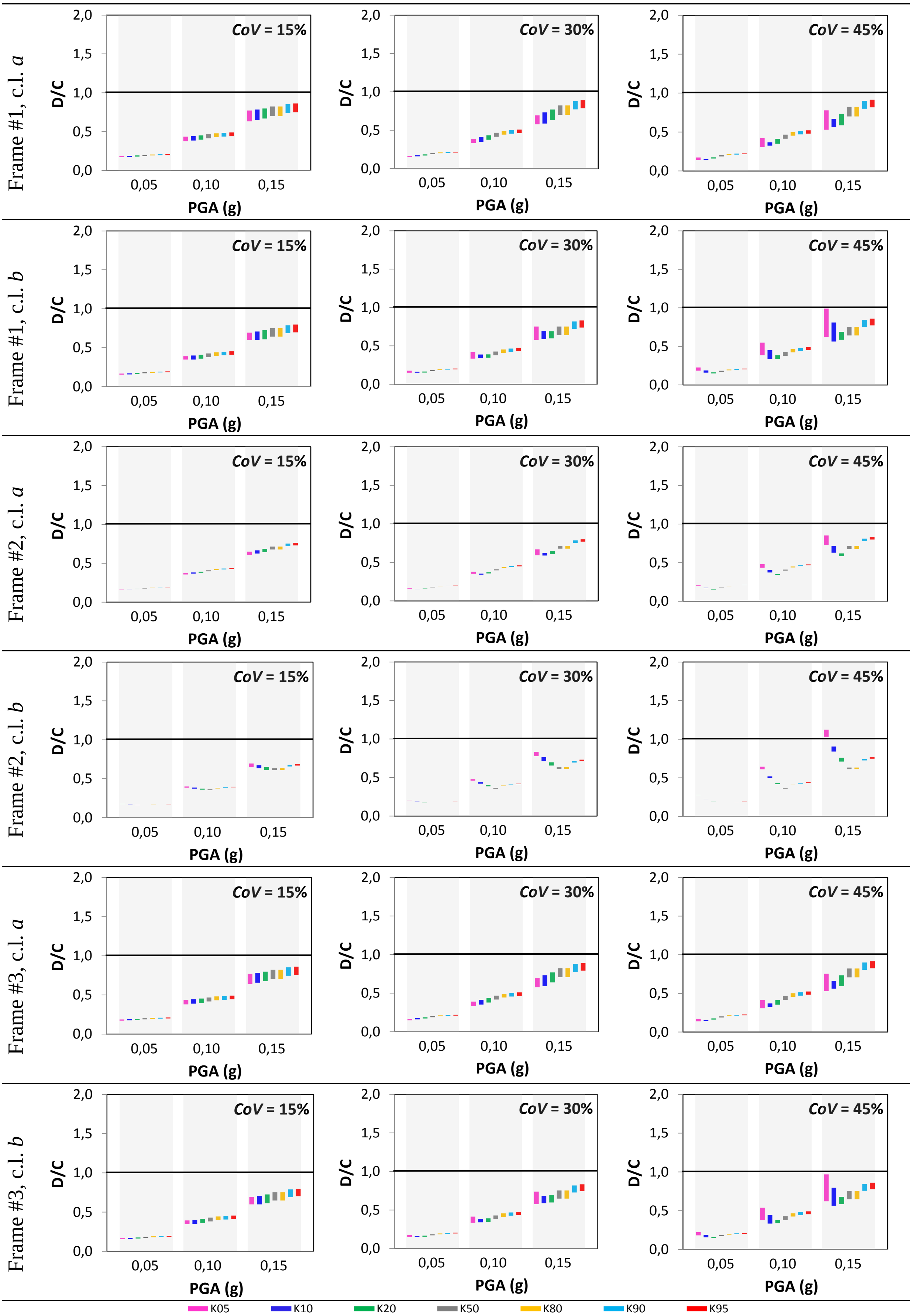


Figure 6. *DL* limit state: performance ranges in terms of chord rotation.

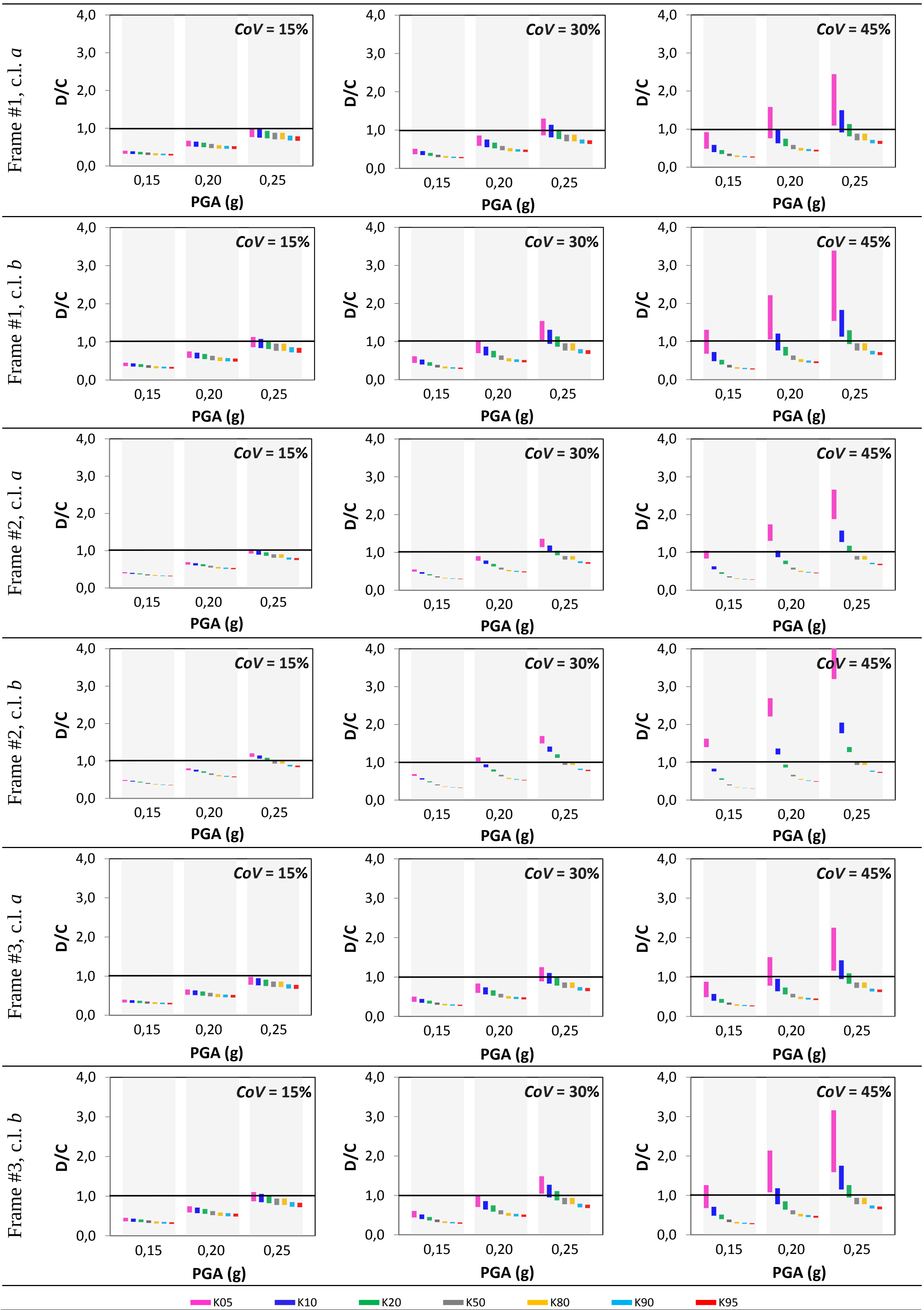


Figure 7. *SD* limit state: performance ranges in terms of chord rotation.

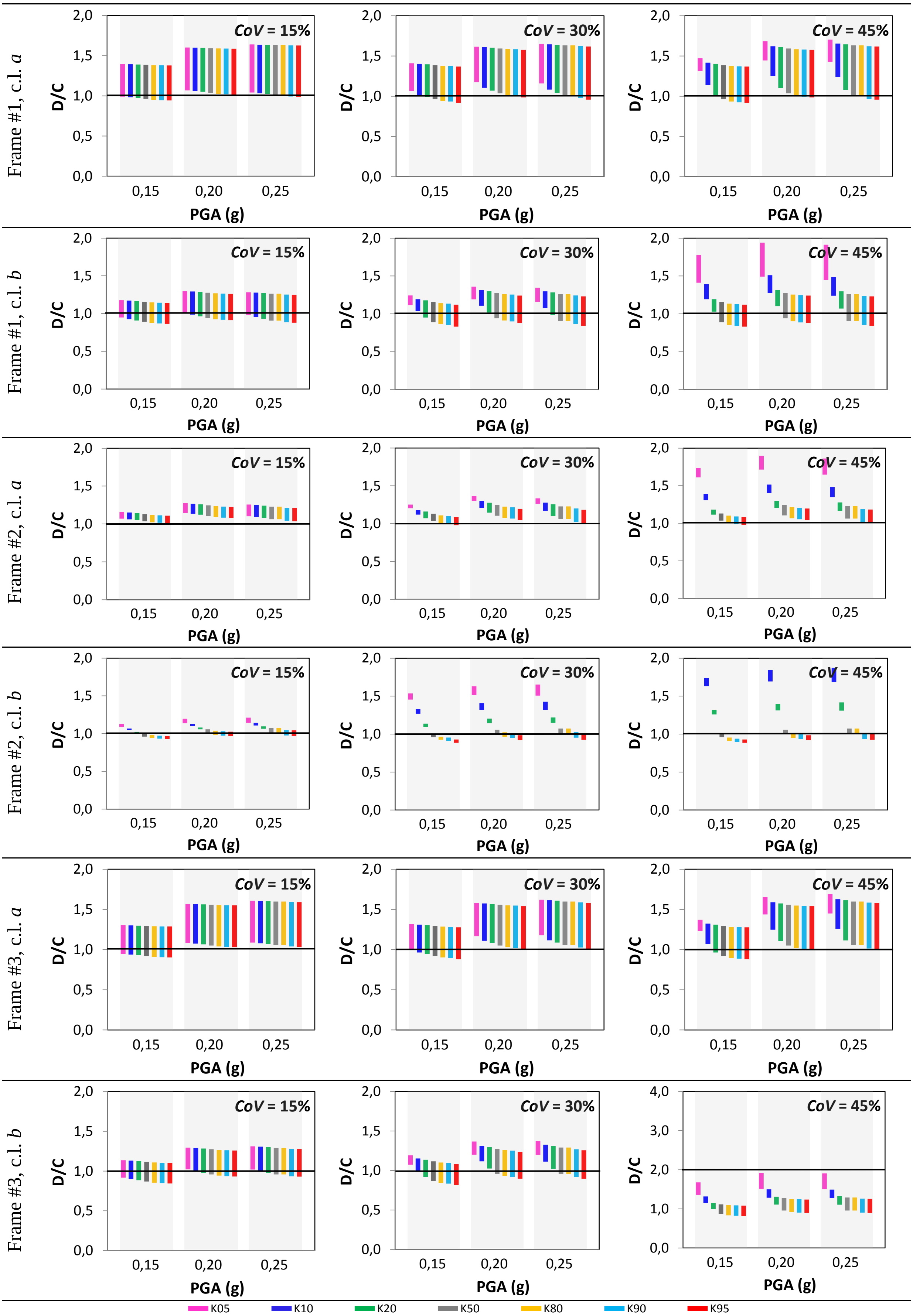


Figure 8. *SD* limit state: performance ranges in terms of shear force.

DL limit state has been verified for PGAs up to 0.15g, while *SD* limit state has been checked for PGA values ranging between 0.15g and 0.25g. For each column the actual range of axial load has been considered in the capacity only, while the seismic demand (chord rotation and shear force respectively) has been assumed with its maximum value. Consequently, for each PGA, a range of values is found for the seismic performance; the amplitude of the range, therefore, can be read as an index of the sensitivity of the seismic performance to ΔN. For sake of brevity, only results referred to two columns for each frame have been shown, belonging to the column lines *a* (side column) and *b* (internal column). Figure 6 shows the D/C ranges found, in terms of chord rotation, for the *DL* limit state. The strength variability largely affects the sensitivity of the seismic performance to the axial load variation. For PGA = 0.15g the case-study exceeds the limit state provided by EC8 only when the lowest percentile of concrete strength and the highest *CoV* are assumed (Frame#2 c.l. b).

The *SD* limit state has been investigated in terms of both chord rotation and shear force. Figure 7 shows the ranges of D/C found for the *SD* limit state in terms of chord rotation. The ranges between minimum and maximum D/C values related to ΔN are much larger than in the *DL* limit state, showing a higher sensitivity of the *SD* seismic performance to the axial load variation. Such sensitivity is relevant especially in the side frames (frames 1 and 3), and it increases when low values of concrete strength are assumed. With reference to the current case-study, when a low concrete strength is assumed, i.e. for high variability (*CoV* = 45%) and low percentiles (K_{05}, K_{10}), ΔN involves an increase of the D/C ratio up to three times the value found by assuming the *mean* strength and exceeding the required limit.

Figure 8 shows the D/C ranges found in terms of shear force. They significantly differ from the ones found in terms of chord rotation as regards the role of the concrete strength on the sensitivity to the axial load variation. The performance ranges expressed in terms of shear force, in fact, are larger for the higher values of concrete strength, especially for high levelsof axial load experienced by the columns.

CONCLUSIONS

In this paper the effects of the axial load variation on the seismic performance of RC structures have been investigated with reference to a case-study, i.e. a 4-storey RC framed building, symmetric about both main directions. The seismic performance, checked at the 1st storey columns, has been measured as the ratio between demand (D) and capacity (C). The capacity of each column has been found at the varying of the axial load and by considering different values of concrete strength, respectively consistent to the EC8 approach and to a probabilistic strength distribution, having the same *mean* value and three different *CoV*s. The capacity has been found for both the *DL* limit state (in terms of chord rotation) and for the *SD* limit state (in terms of chord rotation and shear force).

For each column, a range of D/C has been found by considering the maximum response found by the time-history analysis and the range of capacity corresponding to the axial load range experienced during the seismic response. The width of each D/C range expresses the sensitivity of the column performance to the axial load variation.

As regards the *DL* limit state, the sensitivity of the seismic performance to ΔN is significant only in the side frames for the highest considered PGA (equal to 0.15g), while the value of the concrete strength has a significant effect in most cases. The case-study complies the EC8 requirements in almost all cases; only when the highest value of *CoV* (*CoV* = 45%) is assumed together with lowest strength percentile (5%), for PGA=0.15g the internal columns belonging to the three frames may present D/C values higher than unity.

The *SD* limit state verification in terms of chord rotation pointed out a high sensitivity of the seismic performance to the axial load variation. Such sensitivity, more relevant in the side frames, increases for low values of concrete strength. For low strength values, i.e. for high variability and low percentiles (K_{05}, K_{10}), the axial load variation plays a crucial role in the seismic performance of the structure, inducing an increase of the D/C ratio up to three times the one obtained adopting the *mean* strength value, i.e. by assuming EC8 procedure. In the internal columns, where the amount of axial load is higher, the D/C ratio varies between 0.7 and 4.0, depending on the assumed concrete strength percentage and the axial load level.

The performance ranges expressed in terms of shear force present a different trend comparing to the other ones, being larger for the higher values of concrete strength, especially for high amount of axial load experienced by the columns.

The obtained results evidenced the important role played by the axial load variation on the evaluation of the seismic performance of structures, underlining the relationship between the effects of axial load variation and the effective concrete strength. Both factors, i.e. the effective amount of axial load during the seismic response of the structure, and a more realistic description of the concrete strength distribution should be carefully evaluated in order to assess the seismic performance of existing buildings.

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