Seismic Approach Design Comparison Between IBC and Italian DM2008

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SUMMARY:
A compliance of a facility design with the Italian applicable norms has given the chance to start a comparison between Italian DM2008 and IBC2009 (with ASCE7 and ACI318) seismic provisions. Different parameters are used into the two different code frameworks, in order to obtain the design ground motion at a certain return period. The inconsistency between the two codes does not come from the comparison of the elastic spectra but from the assessment of the differences between the design spectra. A further second study made onto different shear walls remarks this difference. Current codes are force-based method applications. The choice of the factor q or R is, even if based on experience evaluated deductions, quite arbitrary and the stiffness of the structure cannot be known up to the end of the design process. A consideration onto the direct-displacement-based method seems to be at least suggested because of its rational seismic approach.

Keywords: Seismic input, structural factor, shear walls, displacement based

1. INTRODUCTION

The subject of this paper is derived from an assessment of the compliance of a facility design with the Italian applicable norms. The scope of the main work is to assess whether the IBC (International Building Code) basis of design and the main calculation procedures are in compliance with the Italian normative requirements or not. Into this framework an analysis of the seismic aspects takes its justification.

This principle is in accordance with the Italian norms stating that, whenever the designer does not abide by them or few others listed therein, it is his duty to prove that with such different assumptions all safety levels are not less than those provided. A comparison of actions, combination factors and combination criteria between the IBC design and the Italian norms has been carried out, in order to assess if the IBC procedure leads to results equal or better than those achievable with the latter.

To deepen then the analysis and the codes comparison, a second study onto different shear walls has been carried out. In this way, the basic difference existing between the two considered groups of norms regarding shear walls design is evident.

Current seismic codes are applications of the force-based design, where the choice of the factor q or R is, even if based on experience evaluated deductions, quite arbitrary and the stiffness of the structure cannot be known up to the end of the design process. A consideration onto the direct-displacement-based method seems to be at least suggested because of its rational seismic approach.

2. CASE PROJECT SEISMIC LOADS ANALYSIS

The taken case project, which is the object of this first study, is a military facility. The building presents an L-shape plan with its longest edges of 82m and 65m. A concrete frame is the main vertical load resisting structure, together with, almost all around the perimeter, shear walls that are also the structures which are there to resist blasting effects and seismic forces. To be noticed that the redundancy of the walls is due to satisfy blasting verification.

2.1 Normative References

The comparison is carried out between two groups of codes:

1. The first group of codes is made of mainly the Ministerial Decree of 14/01/08 (so called DM2008) and the Circular No. 617 of 02/02/09 and, as integration, the Italian Law No. 1086 of 05/11/71 for concrete, the Italian Law No. 64 of 02/02/74 and the L.R. No. 16 of 11/08/09 for seismic; furthermore, in absence of instructions the use of the following references is allowed: European norms (structural Eurocodes EN) and Instructions by the Italian National Research Committee (CNR). For seismic aspect the Ministerial Decree is the main reference.
2. The second group is made of mainly the International Building Code (IBC) 2009 edition and, as integration, ASCE7 (Minimum Design Loads for Buildings and Other Structures) and ACI318 (Building Code Requirements for Structural Concrete) are considered.

2.2 Compliance Criteria

The compliance is assessed via an analysis carried out over the following components of the engineering structural check procedure: general basis of design and assumptions; characteristic actions; combination factors.
It will be assessed whether the design is satisfying both groups of norms at the same time. If so, then the IBC design process is assumed to guarantee, for the correspondent aspect, a safety level equal or better than the one that would be obtained using the Italian references.
This criterion is in accordance with the Italian Ministerial Decree 14/01/08 § 12: “Possono essere utilizzati anche altri codici internazionali, purché sia dimostrato che garantiscano livelli di sicurezza non inferiori a quelli delle presenti Norme tecniche” (translation: other international codes can also be used, only if it is demonstrated they ensure safety standards not inferior than those of these Technical Standards).

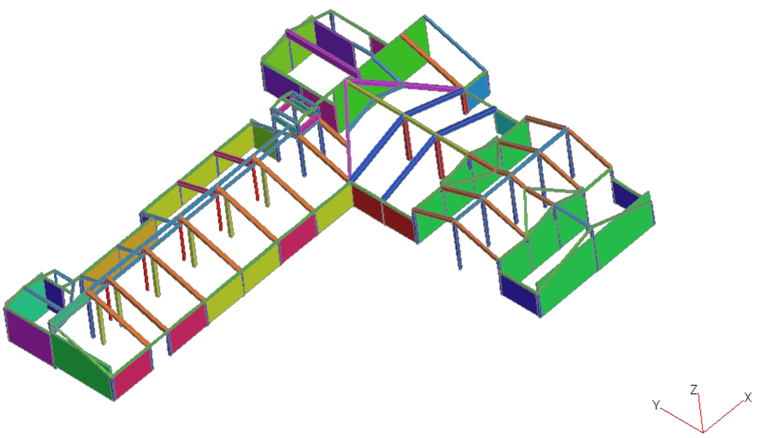

Figure 2.1. Military facility 3D FEM model

Everywhere consistent, the compliance of each issue will be quantified via a safety factor (SF), i.e. the ratio between the considered engineering quantity, calculated in accordance with the original normative references, and the correspondent one calculated according with the national Italian norm. Therefore SF>1 shows the percentage of redundancy of the original reference versus the Italian norm; vice versa SF<1 shows a less performing safety level of the Italian reference versus the original code.

2.2 Seismic Input Definition

The two groups of codes that have been analysed present different parameters nomenclature but at the end the outcome is the same: an elastic spectrum and a design spectrum.

2.2.1. Fist group of codes: DM2008

For the considered location where the facility is desired to be built, the Italian DM2008 gives the parameters which are presented in Tab. 2.1: a_g is the Peak Ground Acceleration; F_O is the horizontal spectral acceleration amplification factor; T_C* is the period when the spectrum constant-velocity starts.

Table 2.1. Values of the mapped parameters a_g, F_O, T_C* for some values T_R, according to DM2008

T_R [years]	**a_g [g]**	**F_O [-]**	**T_C* [s]**
30	0,062	2,484	0,240
50	0,083	2,466	0,257
72	0,100	2,445	0,269
101	0,119	2,424	0,282
140	0,139	2,413	0,292
201	0,164	2,402	0,309
475	0,237	2,417	0,329
975	0,320	2,414	0,347
2475	0,459	2,402	0,374

Obviously, T_R is the return period of the design seismic event. The decision of this value is connected to the use class of the structure and to the nominal service life of the structure. For structures with regular crowd DM2008 states a Use Class II, that yields to a Use Class parameter C_U=1. For structures of normal importance DM2008 suggests a Nominal Service Life of 50 years. The Reference Service Life for the seismic event is then V_R = C_U V_N = 50 years. This value is strictly connected with the return period by the formula:

$$T_R = -\frac{V_R}{\ln\left(1 - P_{V_R}\right)} \tag{2.1}$$

P_{V_R} is the exceeding probability of the design ground motion into the reference service life and it depends of the limit state to be considered. For an ultimate limit state P_{V_R} =10%, that means having a Return Period for the design ground motion of 475 years.

According to DM2008, the facility is going to lay onto a soil site class C, i.e. coarse-grained thickener soil or fine-grained stiff soil ($180 \leq v_s \leq 360$ m/s). This classification determines a Soil Factor of S= 1,70- 0,60$F_O \cdot a_g/g$=1,356.

DM2008 spectrum equations are:

$$S(T) = a_g \cdot S \cdot \eta \cdot F_O \cdot \left[\frac{T}{T_B} + \frac{1}{\eta} \cdot \frac{1}{F_O}\left(1 - \frac{T}{T_B}\right)\right] \text{ for } 0 \leq T \leq T_B \tag{2.2}$$

$$S(T) = a_g \cdot S \cdot \eta \cdot F_O \text{ for } T_B \leq T \leq T_C \tag{2.3}$$

$$S(T) = a_g \cdot S \cdot \eta \cdot F_O\left(\frac{T_C}{T}\right) \text{ for } T_C \leq T \leq T_D \tag{2.4}$$

$$S(T) = a_g \cdot S \cdot \eta \cdot F_O\left(\frac{T_C \cdot T_D}{T^2}\right) \text{ for } T_D \leq T \tag{2.5}$$

T_B is the period when the plateau at constant acceleration of the spectrum starts and T_C is the period when this plateau ends (T_B=T_C/3=0,166s and T_C=1,05 $(T_C*)^{-0,33}$ · T_C*=0,499s). T_D is the so-called corner period of the spectrum (T_D=4a_g/g+1,6=2,548s). Furthermore, η is the damping correction factor and it is unitary for the elastic spectrum of a concrete structure, while it is 1/q for the design spectrum, where q is the Structural Factor.

For large shear walls which are in charge of most of the seismic horizontal action, in accordance with DM2008 §7.4.3.1, the required Ductility Class is CDB (i.e. medium ductility). For shear wall structures DM2008 states the structural factor is q=3 ,while for squat walls the Over Strength Factor Ω_0=MIN{q;1,2}=1,2.

2.2.2. Second group of codes: IBC2009

For the considered location where the facility is desired to be built, the IBC2009 gives the parameters which are presented in Tab. 2.2: S_S is the Spectral Acceleration for Short Period; S_1 is the Spectral Acceleration at 1-second Period.

Table 2.2. Values of the mapped parameters S_S and S_1 according to IBC

S_S	115% g
S_1	46% g

For buildings not designated as essential nor representing a substantial hazard to human life in the event of failure IBC2009 states an Occupancy Category II that implies a unitary Importance Factor (multiplier of the seismic effect).

According to IBC2009, the facility is going to lay onto a soil site class D, i.e. stiff soil profile (180≤v_s≤360 m/s). Consequently, for this site class, combining S_s and S_1 values it is possible to respectively obtain the site coefficients F_a=1,04 and F_v=1,54. Finally the Design Spectral Acceleration Parameters are S_{DS}=2/3$F_a S_S$=0,797g and S_{D1}=2/3$F_v S_1$=0,472g. The seismic design category of the building, in the light of the previous parameters definition, is D.

IBC2009 spectrum equations are:

$$S(T) = \frac{S_{DS}}{\left(\frac{R}{I}\right)}\left[0,4 + 0,6\frac{T}{T_0}\right] \text{ for } 0 \le T \le T_0 \tag{2.6}$$

$$S(T) = \frac{S_{DS}}{\left(\frac{R}{I}\right)} \text{ for } T_0 \le T \le T_S \tag{2.7}$$

$$S(T) = \frac{S_{D1}}{\left(\frac{R}{I}\right)}\left(\frac{1}{T}\right) \text{ for } T_S \le T \le T_L \tag{2.8}$$

$$S(T) = \frac{S_{D1}}{\left(\frac{R}{I}\right)} \cdot \frac{T_L}{T^2} \text{ for } T_L \le T \tag{2.9}$$

T_0 is the period when the plateau at constant acceleration of the spectrum starts and T_S is the period when this plateau ends (T_0=0,2S_{D1}/S_{DS}=0,118s and T_S= S_{D1}/S_{DS}=0,592s). T_L is the so-called corner period of the spectrum and it is taken equal to T_D of the Italian norm DM2008. Furthermore, R is the Response Modification Factor which depends of the structural system and it equal to 6 for special reinforced concrete shear walls. Furthermore, the Over Strength Factor Ω_0=2,5.

In Tab. 2.3 we can find the principal parameters which have been used to carry out the project case design compliance; it is mainly summarizing what it has been already stated into the previous paragraphs of this paper. The key comparison is between the DM2008 structural factor and the IBC2009 response modification factor, i.e. the main factors to be used into the two codified force-based methods of design.

Table 2.3. DM2008 - IBC2009: seismic input parameters comparison

DM 2008	**IBC 2009**
Use Class II: structure with regular crowd → C_U=1	**Occupancy Category II:** buildings not designated as essential nor representing a substantial hazard to human life in the event of failure
Nominal Service Life V_N=50years	**Seismic Importance Factor** I=1
Mapped parameters: PGA horizontal spectral acceleration amplification factor F_O spectrum constant-velocity period start T_C*	**Mapped spectral response accelerations:** S_S Spectral Acceleration for Short Period S_1 is the Spectral Acceleration for a 1-second Period
Site Class C: coarse-grained thickener soil or fine-grained stiff soil (180≤vs≤360 m/s)	**Site Class D:** stiff soil (180≤vs≤360 m/s)
Seismic-force-resisting system: shear walls	**Seismic-force-resisting system:** special reinforced concrete shear walls
Structural Factor q=3	**Response Modification Factor** R=6
Over strength factor Ω_0=MIN{q; 1,2} for squat walls	**Over strength factor** Ω_0=2.5

2.4. Project Case Spectra Comparison

The comparison is based not only on the plateau (i.e. maximum) value but also on the whole extension of the response spectrum, since the facility structure is supposed to be so stiff that its natural period (the 1st period) might be in the ascending stretch (behaviour typical for extremely stiff structures like this one).

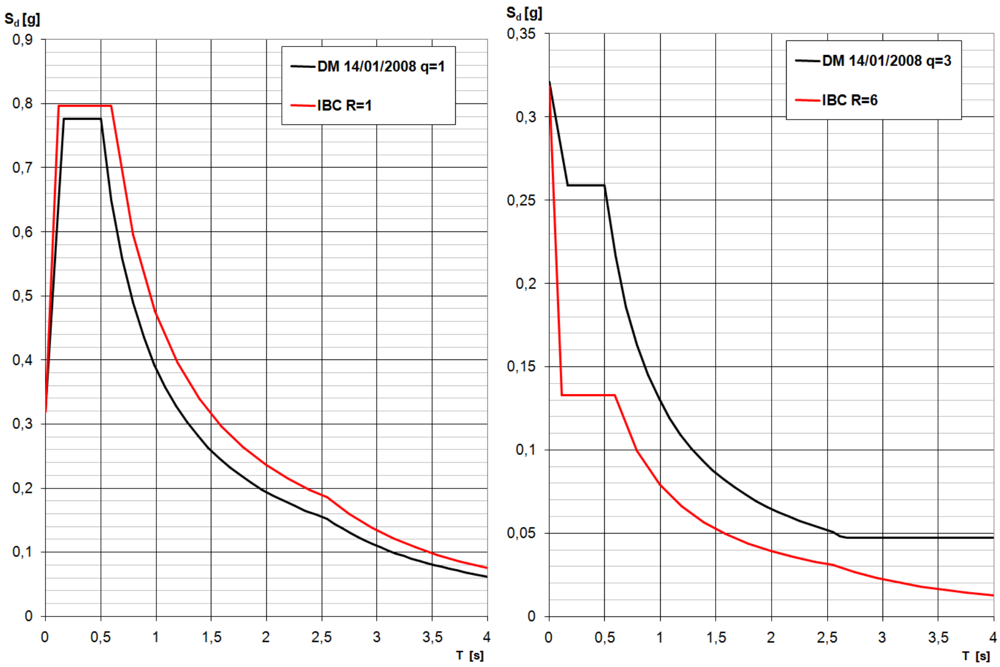

Figure 2.2. Elastic and design spectra comparison between DM 14/01/2008 and IBC

As reported in Fig. 2.2, the IBC design spectrum is far less conservative that the correspondent Italian spectrum (SF based on the plateau = 0.133 / 0.259 = 0.51 << 1.00).

In order to investigate the origin of the difference, a survey has been carried out over the calculation procedure leading to the final design parameters both in the IBC and Italian DM norms.

The results show that, if the basic (i.e. elastic, not factored) design values are compared, the two codes lead to similar forces. In other words the two procedures provide similar elastic design spectra, with the IBC version slightly more conservative than the Italian one (Fig. 2.2): SF based on the plateau = 0.797 / 0.777 = 1.03 > 1.00, and the IBC spectrum remains above the Italian one for higher and shorter periods.

The strong difference is due to the assumption of a relevant Response Modification Factor (R = 6) following IBC provisions: this choice is directly connected with the declared Basic Structural System (Building Frame Systems), but in our opinion it is not consistent with the actual horizontal resisting system that is rather a very stiff bearing wall system.

In the Italian norm a far smaller structural factor q (correspondent to R) can be assumed in such cases. According with the prescriptions in DM2008 §7.4.3.2, the maximum value for q should be 3.00, but taking into account the redundancy of shear walls in this facility an even smaller factor would be safer, due to the low yielding capacity of the system in each direction.

With the current assumptions, IBC does not comply with the Italian norm as far as earthquake action is concerned. Nonetheless, the survey carried out over the codes shows that a full compliance can be achieved simply by assuming a lower R factor in the IBC design.

2.5. Design Base Shear Comparison

Next step into the comparison is to compare the base design shear for the two considered cases: ~4200kN is the shear forces (for the tested shear wall) according to both DM2008 and IBC2009. The outcome is unexpected since a much bigger shear force is expected, adopting the IBC norm because of what has been just declared in the previous paragraph. The reason of this behaviour might be found onto the structure high stiffness, in fact very low periods move the study onto the PGA zone. This facility study case, then, would not be well representative for this codes' comparison and further study is required and it is showed into next chapter.

3. CANTILEVER WALLS COMPARISON

The need to investigate further the DM2008-IBC2009 comparison regarding the shear wall seismic design has conducted to analyse the cantilever walls schematically represented at Fig. 3.1 and with their features tabulated at Tab. 3.1.

The walls have the same tributary floor mass of 60 tonnes and gravity load of 200kN at each level. The carried out analysis has been made with a finite element method software in order to produce the modal superposition analysis.

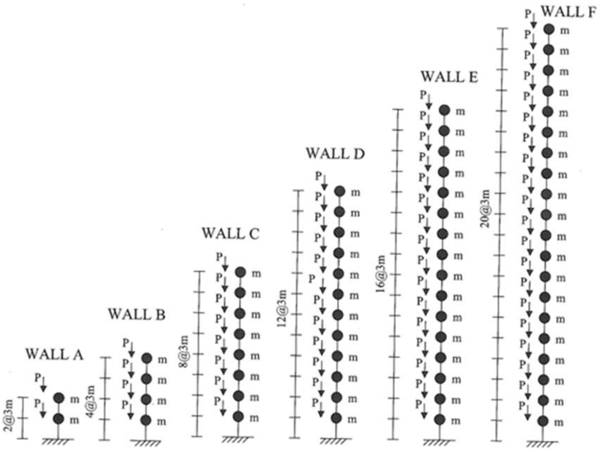

Figure 3.1. Cantilever walls investigated into the analysis [Priestly et al.]

Table 3.1. Cantilever walls features

Wall type	**Storey N**	**b [m]**	**l_w [m]**	**W_{tot} [kN]**
A	2	0,20	2,0	1260
B	4	0,20	2,5	2550
C	8	0,20	3,3	5196
D	12	0,25	4,0	8100
E	16	0,25	5,0	11100
F	20	0,30	5,6	14520

Table 3.2. Shear and bending moment calculation according DM2008 and IBC2009

Wall type	**I=0,5I_{gross}**	**T_1 [s]**	**V_{ASCE} [kN]**	**V_{DM2008} [kN]**	**ΔV [kN]**	**M_{ASCE} [kNm]**	**M_{DM2008} [kNm]**	**ΔM [kNm]**
A	0,067	0,312	356	406	51	680	1320	640
B	0,130	0,739	577	596	19	1820	2965	1145
C	0,299	1,567	554	802	247	2820	4685	1865
D	0,667	2,602	925	1278	353	4445	7385	2940
E	1,302	3,290	863	1950	1088	6560	12740	6180
F	2,195	3,995	1013	2220	1208	8960	19950	10990

Base shear are calculated following the prescriptions that are declared into the IBC (that recalls the ASCE) and into the DM2008. From the Tab. 3.2 it is evident that base shears are different and the higher is the first natural period, the higher is the difference between the calculated values: DM2008 appears to be more conservative than the IBC.
A parallel comparison has been made for the bending moment with same qualitative results.

The elastic spectra coming out of the two groups of codes are substantially equivalent, while the design spectra become crucial to determine the final seismic design actions (e.g. base shear forces, base bending moment, etc.). That is the reason why the choice of the Structural Factor or the Response Modification Factor should be done cautiously. How do the codes state their values? Where is the designer choice that yields into a reasonable outcome? Why an American designer would have found a so-different outcome than what his Italian colleague would have obtained?

4. CONCLUSIONS

4.1. Force-based method criticism

The choice of the factor q or R is, even if based on experience evaluated deductions, quite arbitrary and the stiffness of the structure cannot be known up to the end of the design process. Force-based methods are the most used and codified methods for seismic design. Here the scheme for designing according to this methodology is shown into Fig. 4.1. Furthermore, some main design criticisms are:

- Stiffness is estimated to determine the period T: stiffness is dependent on strength which cannot be known until the end of the design process (red rectangle at Fig. 4.1)
- Allocating seismic force between elements based on initial stiffness is illogical because different elements might not yield simultaneously (yellow rectangle at Fig. 4.1)
- The assumption that unique force-reduction factors (q or R) are appropriate for a given structural type and material is at least disputable (purple rectangle at Fig. 4.1)
- Displacements check is performed only at last

Besides all of that, if we take into account an analysis carried out with aim of deepening the design displacement values according the principal design code, it can become intuitive to see how difficult is having a homogeneity of results. Fig. 4.2 is self-explicative, then why not starting straight from a design displacement?

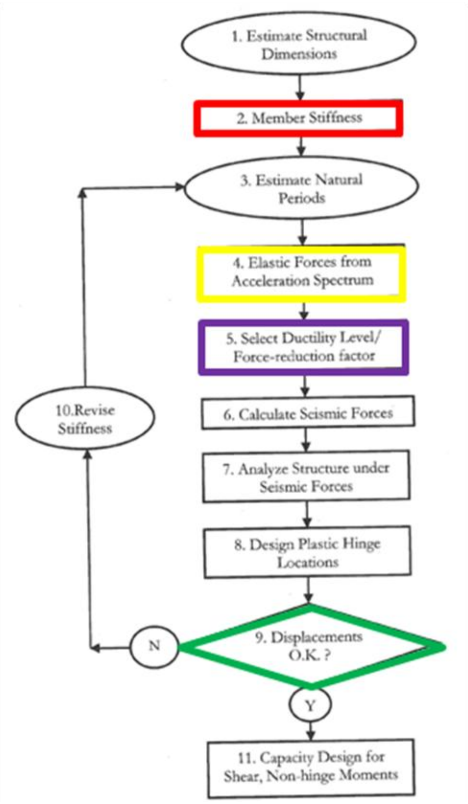

Figure 4.1. Force-based flow chart [Priestly et al.]

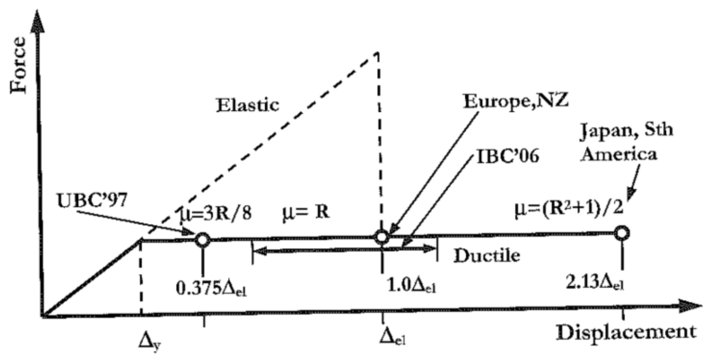

Figure 4.2. Estimates of Design Displacement from Different Force-Based Codes for R=4 [Priestly et al.]

3.2. Displacement-based Method Milestones

The displacement-based method milestones can be resumed as follows:

- For a given geometrical section there is a constant yield curvature behaviour
- Empirical calculation (through calibrated laws) determines the hysteretic damping ξ_{hyst}, which depends on the hysteresis rule appropriate for the structure being designed; the hysteretic damping summed to the elastic damping (which is usually the only taken into account into the force-based method) gives the equivalent damping which has to be used to correctly calibrate the spectrum
- No R (or q) force reduction factor is used, but elastic displacement spectra with adequate equivalent damping
- The design is made onto the secant stiffness K_e

3.3. Suggestions For Further Research

In the opinion of the authors there is a wide variety of issues related with the topic which might be further investigated.

Despite the lack of representativeness of the abovementioned case history, one of the most promising fields of application of the present study would be a complete FE model. A facility with lower global stiffness would provide the chance to repeat the comparison between the norms with the use of the displacement based method. Under this assumption the main reason of bad conditioning to the study - say the structural factors R or q - would be removed, and a deeper focus on the results of the further design steps would be possible. In particular, the present study allowed the authors to sense the many differences lying between the IBC and the Italian DM when it comes to detail design, therefore an effort on such a focus is expected to be of great interest.

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