

PAPER • OPEN ACCESS

Direct Displacement-Based Design (DDBD) applied to dual wall-frame buildings and steel concentric braced frames

To cite this article: W. Ccahuana *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **910** 012013

View the [article online](#) for updates and enhancements.

You may also like

- [Performance Based Seismic Design of Steel Structure Using Non-Linear Dynamic Analysis](#)
Choimei Moileen Semdok and Babita Saini
- [A review of retrofitting in the structural steel buildings using bracing systems](#)
Zainab Q Hassan and Saad Al-Wazni
- [Evaluating the ductility characteristics of self-centering buckling-restrained shape memory alloy braces](#)
Hamdy Abou-Elfath



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Direct Displacement-Based Design (DDBD) applied to dual wall-frame buildings and steel concentric braced frames

W. Ccahuana¹, J. Coronel¹, and J. Soto¹

¹ Universidad Peruana de Ciencias Aplicadas

pcciesot@upc.edu.pe

Abstract. One of the most efficient seismic design methodologies is Direct Displacement Based Design (DDBD) because it considers the inelastic range of the structure. There are several investigations on the application of this methodology in frames, structural wall and bridges, but those related to steel structures with concentric bracing are scarcer. The objective of this investigation is to determine the damping parameters and the seismic responses of a dual concrete building and one of concentrically braced steel frames, to later compare their base loads and displacements. The procedure first determines the design offset for the 1GDL model; then the desired responses are obtained by this displacement. This methodology uses an effective stiffness, which is composed of an elastic and an inelastic state of the structure to determine seismic responses.

1. Introduction

The large number of earthquakes in the Ring of Fire and its high population density forces Civil Engineering to investigate and propose new and more precise methods when making the seismic design of a structure.

A first reference is that of Priestley et al. [1], which established the theoretical guidelines on Displacement Based Design (DBD) with a special methodology called Direct Displacement Based Design (DDBD), which is what will be used in this work.

Subsequently, research was carried out on the application of this methodology in steel frame buildings. Connections and concentric bracing (CBF) [2] in the structures have a great impact on the damping of these, which is demonstrated by the article. A structure with CBF type bracing has a great increase in lateral stiffness, so its displacement profile is much smaller than one without bracing [3]. All values were corroborated with the American Society of Civil Engineers [4].

With respect to the application of the DDBD method in buildings with double wall frames, the influence of the cutting walls on the displacement profile of the structure is used. In addition, unlike steel frames, in a dual wall-frame building with cracks there is an increase in its damping due to the cracked inertia of its structural elements.

In this research, two buildings of similar architectural distribution have been analyzed using this seismic design methodology, but with different structural systems: dual wall-frame buildings and steel concentric braced frames. Since this design only applies to axes and not to the structure as a whole, the most influential and best represented axis for the design in both structural systems has been chosen. The damping in both cases will be obtained from the guidelines proposed by Priestley [1]; however, some modifications have been made, corresponding to investigations that support a more specific



damping. Finally, the answers are presented as shear and basal moment which will be compared and analyzed.

2. Method

Seismic analysis will be carried out using the DDBD methodology to two structural systems following the guidelines established by Priestley [1], to then compare the results in displacements and basal forces. The structure's damping behavior will be included through the results of previous investigations [5], [6], [7]; Damping is an important parameter, since it is the one that most influences the seismic response.

The damping used in structural systems are the following:

- Dual wall-frame system:

$$\zeta_w = 0.05 + 0.444\left(\frac{\mu-1}{\mu\pi}\right) \quad (1)$$

Source: Priestley Et al. 2007

- Steel frames system:

$$\zeta_w = 0.05 + 0.565\left(\frac{\mu-1}{\mu\pi}\right) \quad (2)$$

Source: Priestley Et al. 2007

Where the parameter μ represents the ductility of system displacement.

3. Results

To validate the investigation, two structural systems were used, which are: Dual system (Figure 1) and steel frame system (Figure 2).

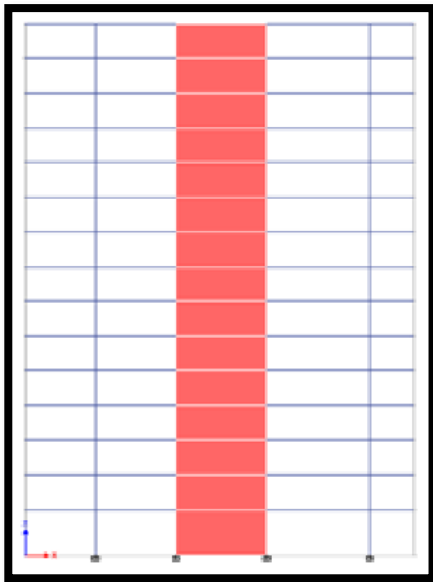


Figure 1. Dual Structure (Source: Own elaboration in Etabs)

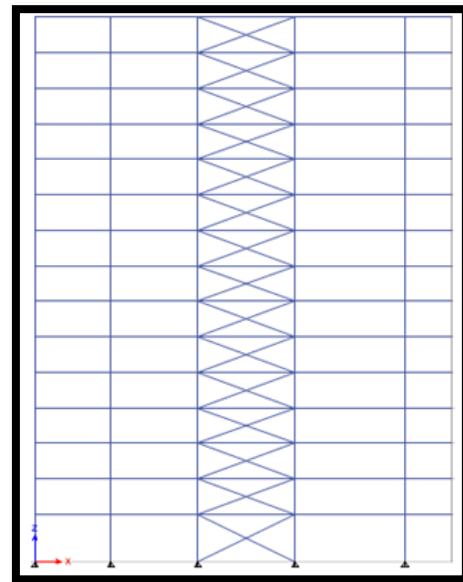


Figure 2. Steel frame structure (Source: Own elaboration in Etabs)

The comparison will be between 2 buildings of 15 levels with the same architectural configuration. The first level will be 4 meters high and the following ones will be 3 meters high. The live loads in each system will be 450kgf / m² for a tributary width of 7m in the beams and an independent dead load per level specified in the following paragraphs.

The dual structural system has a dead load of 600 kgf/m² on the first level and 500kgf/m² on the following levels. The structural elements will have the following sections: 60x80 cm columns, 30x50 cm beams and 30cm cutting walls. The amount of steel in the structural elements will be evaluated through the Etabs program. The concrete used is 280kgf/cm² in verticals and 210kgf/cm² in horizontals. The amount of steel used will be 1% for columns and beams 0.0018.

The structural system of steel frames has a dead load of 400kgf / m² on the first level and 300kgf/m² on the following levels. The structural elements will have the following sections: HSS20x20 metal columns, T 15x15 beams and HSS8x8 bracing. The connections will be of the cut type.

3.1. DDBD seismic response in dual system

The theoretical guidelines followed in this research are those proposed by Priestley [1]. Next, the results obtained under the DDBD method and non-linear Pushover analysis method are presented in order to compare them. A drift limit state of 2.5% damage prevention is considered.

The dual structural system that uses the DDBD methodology has a baseline shear of 1772kN, greater than the non-linear methodology by 54.26% as seen in Figure 3. A linear tendency is observed in Figure 4. The story moments at the base are 53927kN-m, greater than the non-linear system by 50.98%, the latter being 36536 kN-m present in Figure 5. The maximum drift obtained with the DDBD method is 2.5%, controlled by the limit state of damage control and a maximum drift of the non-linear methodology at 0.44% as seen in Figure 6.

The displacement through the DDBD is 110 cm in the limit state of damage prevention compared to the 4.4 cm obtained from the non-linear methodology observed in the capacity curve of Figure 7. These results are due to the simplicity of the DDBD methodology that does not consider the hysteretic effect of the structure and, consequently, greater displacements are acquired.

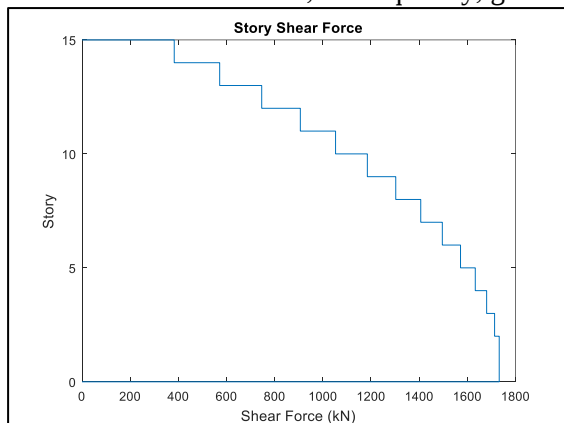


Figure 3. DDBD shear forces (Source: own source)

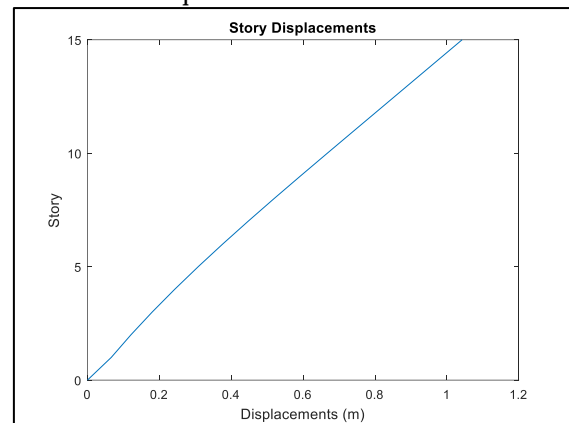


Figure 4. DDBD displacements (Source: own source)

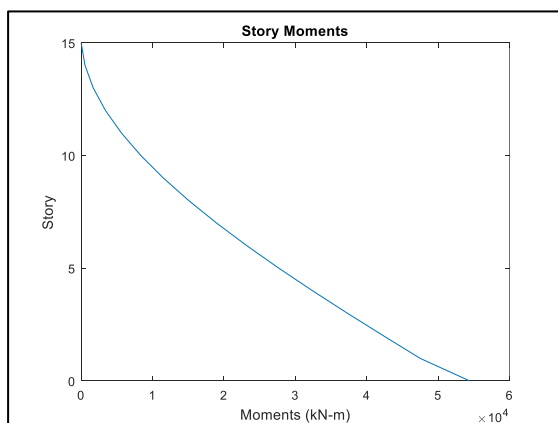


Figure 5. DDBD bending moments (Source: own source)

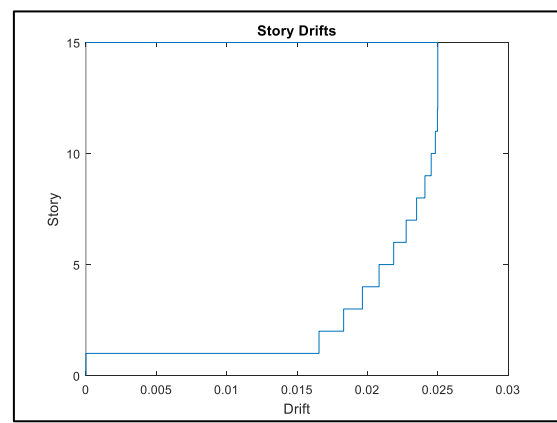


Figure 6. DDBD drifts (Source: own source)

It should be mentioned that for the non-linear Pushover methodology, hinges were used at 0.1 and 0.9 of the length of the columns and beams obtaining an effective stiffness of 2829 kN/m. In contrast, in the DDBD methodology an effective stiffness of 2475 kN/m was calculated, this being inferior to that obtained in the non-linear analysis. This imprecision implies a considerable increase in the forces and, consequently, in the sections of the structural elements.

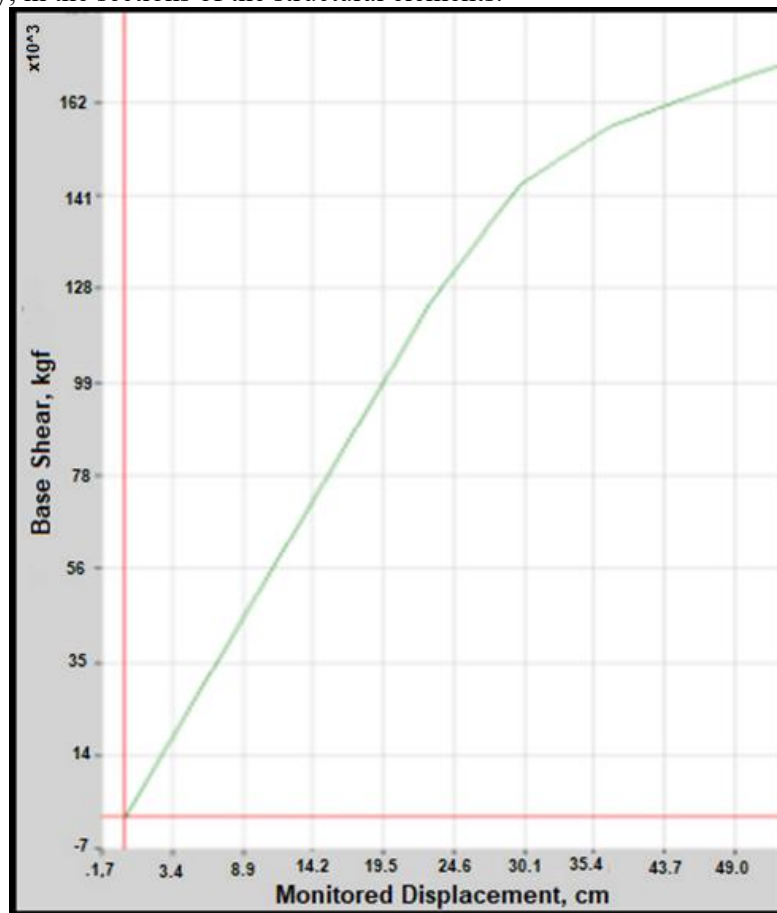


Figure 7. Pushover capacity curve for dual system (Source: own elaboration in Etabs)

3.2. DDBD seismic response in steel frames system

In the same way as in the dual system, the theoretical guidelines followed in this investigation are those proposed by Priestley [1]. Next, the results obtained under the DDBD method and non-linear Pushover analysis method are presented in order to compare them. A drift limit state of 2.5% damage prevention is considered.

The steel frame system using the DDBD methodology presents a baseline shear of 2024 kN, which is greater than the non-linear methodology by 54.26% and is observed in Figure 8. The story displacements are shown in Figure 9.

The moments at the base are 18927 kN-m, greater than the non-linear system by 50.98%, the latter being 12536 kN-m present in Figure 10. The maximum drift obtained with the DDBD method is 2.5% controlled by the damage control limit state and a maximum drift of the non-linear methodology at 0.44% as it is shown in Figure 11.

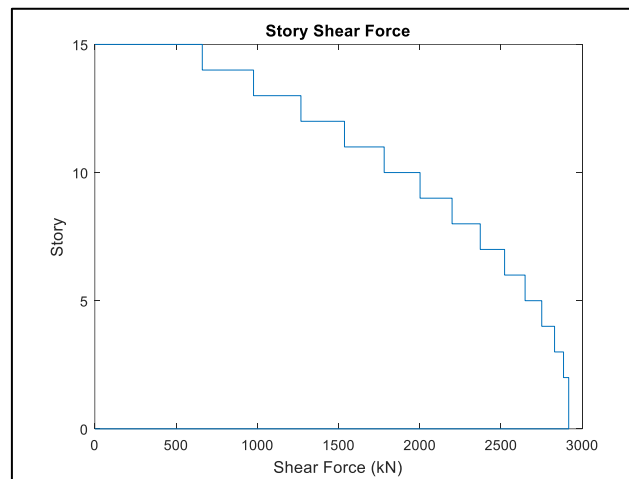


Figure 8. DDBD shear forces (Source: own source)

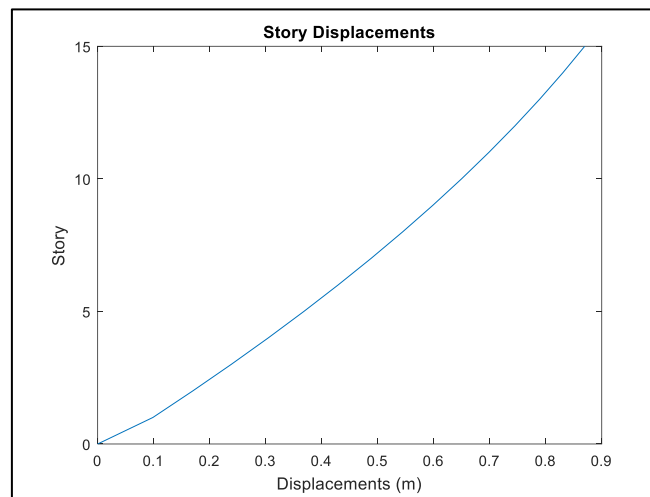


Figure 9. DDBD displacements (Source: own source)

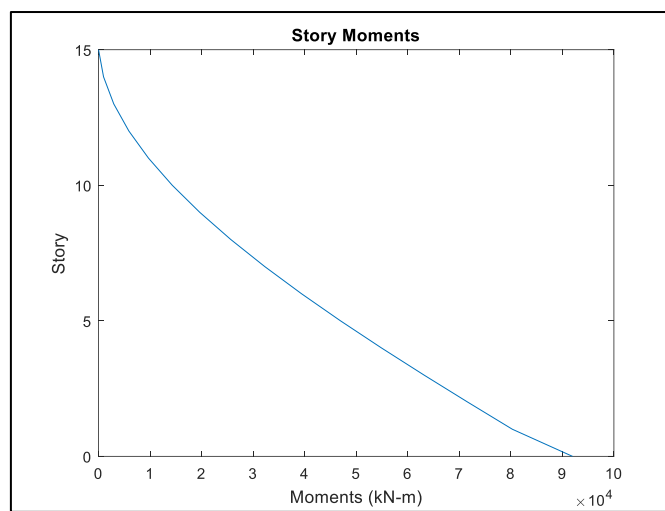


Figure 10. DDBD bending moments (Source: own source)

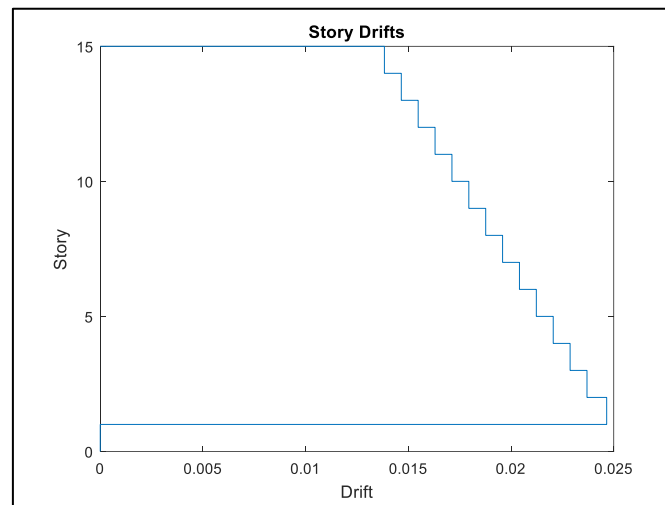


Figure 11. DDBD drifts (Source: own source)

The displacement using the DDBD is 118 cm in the limit state of damage prevention compared to the 4.4cm obtained from the non-linear methodology observed in the capacity curve of Figure 12. These results are due to the simplicity of the DDBD methodology that does not consider the hysteretic effect of the structure and, consequently, greater displacements are obtained. It is necessary to mention that for the non-linear Pushover methodology, hinges were used at 0.1 and 0.9 of the length of the columns and beams obtaining an effective stiffness of 4532 kN / m in the capacity curve. Instead, in the DDBD methodology calculated an effective stiffness of 3248 kN / m, this being inferior to that obtained in the non-linear analysis. This imprecision implies a considerable increase in the forces and, consequently, in the sections of the structural elements.

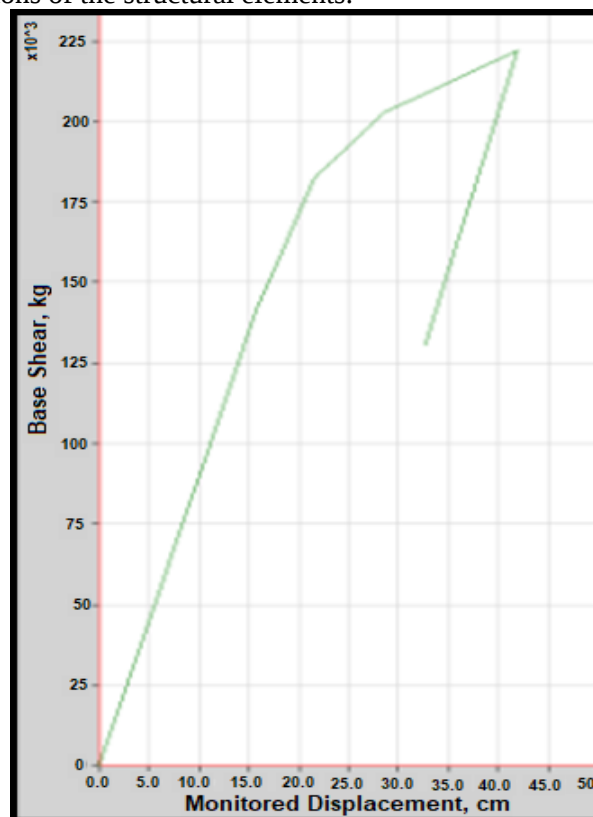


Figure 12. Pushover capacity curve for Steel frames (Source: own elaboration in Etabs)

4. Conclusions

The displacements are the same in the two structural systems by condition of the DDBD methodology, in which it is established that the maximum displacement in the two structures will be 2.5% of the height of the building per damage prevention limit state according to Priestley[1].

The basal shear force in the steel frame is greater than the dual system in 6%. In ideal conditions, being the most ductile steel structure, it allows greater displacements. However, the system is not ideal and has a damping that decreases its effective period and consequently its basal forces. The period obtained in the contributed steel system was 3.96 s and 5.48 s in the dual system.

The damping in the steel structure is 13% and that of the dual system is 18%. The damping in a dual system increases due to the cracking of the structural elements of the concrete and in a system provided with steel it increases mainly due to the buckling of its steel columns.

The DDBD methodology allows to avoid oversizing in structural design of the structure. This is due to the fact that this methodology falls within the inelastic range of the structure and we do not assume that all its behavior is linear, which confirms its proximity to the real effects with the comparison with the capacity curve obtained from the non-linear Pushover analysis. When it is considered that the behavior of a structure is always linear, it is when oversize begins to exist due to an excessive increase in seismic forces. This happens because non-linear behavior, such as cracking the structure, releases efforts and makes the ultimate design efforts less.

5. References

- [1] M. Priestley, G. Calvi and M. Kowalski, “*Displacement-Based Seismic Design of Structures*” IUSS PRESS.
- [2] S. Salawadeh, T. Ryan, B. Broderick and J. Goggins, “*DDBD assessment of steel CBFs using full scale shake table tests with realistic connections*” Journals of Construction.
- [3] M. Ferraioli and A. Lavino, “*A Displacement-Based Design Method for Seismic Retrofit of RC Buildings Using Dissipative Braces*” Mathematical Problems in Engineering
- [4] *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE 41-13).
- [5] R. Abadi and O. Bahar, “*Investigation of the LS Level Hysteretic Damping Capacity of Steel MR Frames Needs for the Direct Displacement-Based Design Method*” Korean Society of Civil Engineers, pp 1-12.
- [6] D. Ranjan, A. Prakash, “*Seismic behaviour of concentrically braced frames designed using direct displacement-based method*” International Journal of Steel Structures.
- [7] M. Al-Mashaykhi, P. Rajeev, K. Wijesundara, M. Hashemi, “*Displacement profile for displacement based seismic design of concentric braced frames*” Journal of Constructional Steel Research.

Acknowledgments

This research has been possible due to constant support from the Civil Engineering Faculty at the Engineering Department of the Universidad Peruana de Ciencias Aplicadas (UPC) in Lima, Peru.