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ACCOUNTING FOR DUCTILITY AND OVER STRENGTH IN SEISMIC DESIGN OF DUAL SYSTEM VERTICALLY I RREGULAR REINFORCED CONCRETE STRUCTURE

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Abstract: This study is conducted to account and evaluate both the over strength and ductility factors on the dual system reinforced concrete structures with regular and irregular pattern in elevation to show their effect on storey shear as well as storey drift. In this study, three 8-storied frame-wall structures (irregular in elevation) and one 8-storied frame-wall structure (regular in elevation) assumed located in a region of high seismicity all with the plan area of 15 x10 meters are analyzed for their responses to lateral loading by applying biaxial analysis in accordance with the Ethiopian seismic code (ES EN 1998:2015) and Ethiopian code for concrete structures (ES EN 1992:2015). The specified 28 day concrete compressive strength of 30 Mpa and the specified yield stress of the steel 420 Mpa were used. The analysis of structures had been carried out by using finite element soft ware ETABS 2016 Ultimate 16.2.1, which is a structural analysis program for static and dynamic analyses of structures. The weight of the systems had been assumed to consist total dead load, *DL* plus 20% of live load, *LL*. The results of this study show the importance of the regularity of building structures regarding over strength in their ability to resist horizontal loads caused by earthquakes.

Keywords: : Reinforced Concrete Structure, Over Strength, Base Shear, Ductility, Biaxial Analysis, Dual System, Storey Drift, Storey Shear.

1. Introduction

A dual system is a structural system in which an essentially complete frame provides support for gravity loads, and resistance to lateral loads is provided by a specially detailed moment-resisting frame and shear walls or braced frames. Both shear walls and frames participate in resisting the lateral loads resulting from earthquakes or wind or storms, and the portion of the forces resisted by each one depends on its rigidity, modulus of elasticity and its ductility, and the possibility to develop plastic hinges in its parts. The moment-resisting frame must be capable of resisting at least 25 percent of the base shear, and the two systems must be designed to resist the total lateral load in proportion to their relative rigidities. In the dual system, both frames and shear walls contribute in resisting the lateral loads. The frame is a group of beams and columns connected with each other by rigid joints, and the frames bend in accordance with shear mode, whereas the deflection of the shear walls is by a bending mode like the cantilever walls. As a result of the difference in deflection properties between frames and walls, the frames will try to pull the shear walls in the top of the building, while in the bottom, they will try to push the walls. So the frames will resist the lateral loads in the upper part of the building, which means an increase in the dimensions of the cross section area of the columns in the upper part of the frame more than what it needs to resist the gravity loads, while the shear walls will resist most of the vertical loads in the lower part of the building. So the distribution of the lateral loads in the top depends on the rigidity of the frames where we suppose a spring support, whose rigidity equals the rigidity of the frames in the top, and the reaction of this spring is the share of the frames, and the rest is the share of the walls. So, the walls are pinned or supported by the frames at the top and fixed at the bottom and they are resisting the seismic loads. So we need to find out the value of this reaction at the top which equals a point load as the share of the frames according to the Macleod Theory (Mitchell and Paultre 1994) then the share of the frames will be distributed to each frame due to its rigidity and position relating to the center of mass taking into consideration the torsion and shear resulting from torsion. (N.Anwar, ACEOMS, AIT, Thailand) has modeled shear walls as truss models in which boundary elements were considered as columns. The dimension of diagonal strut was considered to be equal to t x t, where "t" is the thickness of shear wall. (Moehle 1984) have studied the failure mechanism and ductility of R.C. frame-shear walls for school buildings by the full-scale experiments. Eight specimens subjected to reversed cyclic lateral loading have been tested to failure. The experimental results, as expected, show that the crack load, yield load, and limit load are superior for specimens with higher concrete strength and frame with wall. In addition, the energy consumption of bare frame is greater than that of dual frame. (Miranda and Bertero 1994) have conducted experimental tests on dual structures. The maximum redistribution of forces and moments occurs at failure in frame wall systems with the stiff walls and the flexible frames.

2. The relation between structural capacity (over strength) and design strength

Over strength is usually defined using over strength factor which is defined as the ratio of the maximum base shear in actual behavior to first significant yield strength in structure. Figure 1 shows a typical relationship between base shear r and top displacement of a structure [11]. Terms used in the figure are v_e; elastic base shear , v_y; yield base shear, v_1; base shear at first plastic hinge and v_d; design base shear.

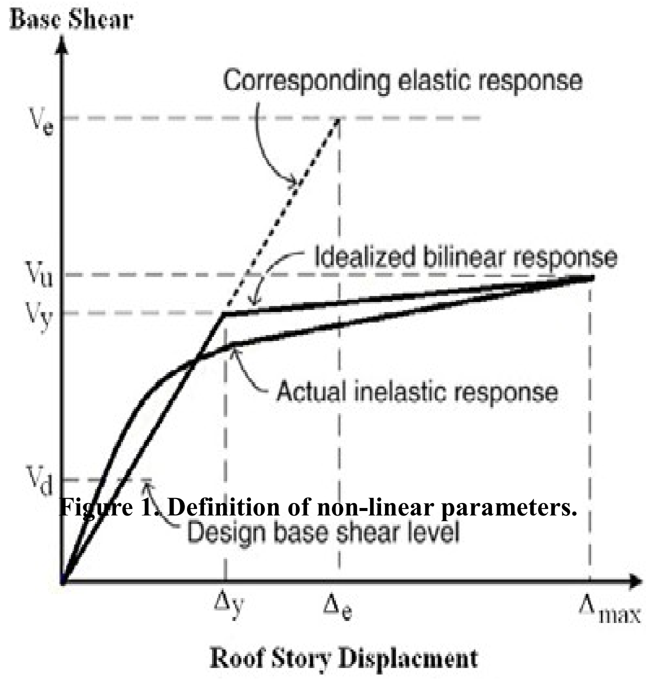


Figure 1. Definition of non-linear parameters.

Figure 1. Definition of non-linear parameters.

2.1. OVERSTRENGHT's ROLE IN SEISMIC DESIGN

Many seismic codes permit a reduction in design loads, taking advantage of the fact that the structures possess significant reserve strength (over strength) and capacity to dissipate energy (ductility) [16].

2.2. Main sources of Over strength

The main sources of over strength are reviewed in other researches [4]. These include: (1) the difference between the actual and the design material strength; (2) conservatism of the design procedure and ductility requirements; (3) load factors and multiple load cases; (4) accidental torsion consideration; (5) serviceability limit state provisions; (6) participation of nonstructural elements; (7) effect of structural elements not considered in predicting the lateral load capacity (e.g. actual slab width); (8) minimum reinforcement and member sizes that exceed the design requirements; (9) Redundancy of the structure and redistribution of forces (stresses) between structural members; (10) strain hardening;

(11) actual confinement effect; and (12) utilizing the elastic period to obtain the design forces.

2.2.1. Abbreviations

DL Dead Load

LL Live Load

ES EN Ethiopian Standard European Norm

DCM Ductile Class Medium

Mpa Mega Pascal

EQx Earth Quake in x direction

EQy Earth Quake in y direction

Str structure

2.2.2. Equations

$\Omega = V_y/V_1$..Equation (1)

$\mu = U_{max}$.. Equation(2)

Where Ω over strength factor

U_{max} maximum story displacement

μ ductility factor

U_{yield} yield story displacement

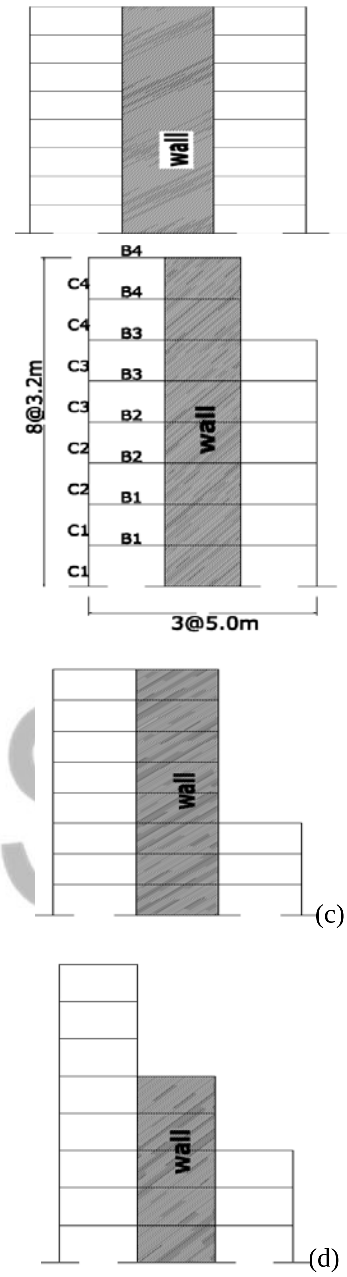
V_{yield} yield base shear

V_1 base shear at first plastic hinge

3. Methodology of the Study

3.1. Materials Constitutive Behaviours and Modelling

In this study, three 8-storied frame-wall structures (irregular in elevation) and one 8-storied frame-wall structure (regular in elevation), all with plan area of 15 x10 meters had been assessed. The structures were analyzed and investigated in accordance with the Ethiopian seismic code (ES EN 1998:2015) and Ethiopian code for concrete structures (ES EN 1992:2015). The specified 28 day concrete compressive strength of 30 Mpa and the specified yield stress of the steel 420 Mpa were used. The analysis of structures had been carried out by using finite element soft ware ETABS 2016 Ultimate 16.2.1 , which is a structural analysis program for static and dynamic analyses of structures, under biaxial seismic excitation analysis. The weight of the systems had been assumed to consist total dead load, *DL* plus 20% of live load, *LL*. The behaviour Factors are as per (ES EN 1998:2015 Table 3.2), q = 3.9, 3.12 ,3.12 ,3.12 for structure 1, 2, 3 and 4 respectively



(a)tructure 1

(b) structure 2

(c) structure 3

(d) structure 4

Fig. 2. Geometry of the structures investigated.

Note: All dual frame structures are 8 storied spaced @ 3.2m vertically except footing columns and 3 bays @ 5m horizontally. All footing columns are spaced @ 3m vertically.

Table 1. *Model dimension size for beams , columns,. Slab and shear wall*

Symbol	Structural Member Name	Concrete Grade	Steel Grade	Section Size (mm)
B1	Beam 1	C 25/30	S 420	600*400
B2	Beam 2	C 25/30	S 420	500*400
B3	Beam 3	C 25/30	S 420	450*400
B4	Beam 4	C 25/30	S 420	400*400
B5	Beam 5	C 25/30	S 420	350*350
C1	Column 1	C 25/30	S 420	600*600
C2	Column 2	C 25/30	S 420	500*500
C3	Column 3	C 25/30	S 420	450*450
C4	Column 4	C 25/30	S 420	400*400
C5	Column 5	C 25/30	S 420	350*350
SW	Shear Wall	C 25/30	S 420	4500*200
Slab	slab	C 25/30	S 420	200

4. STATIC PUSHOVER ANALYSIS

Static pushover analysis was performed bi axially to evaluate the impact of vertical irregularity on ductility and over strength of vertically irregular structures under investigated. The four structures were subjected to static pushover analysis for the gravity (dead and live load) and earthquake forces tributary to them. The gravity loads are held constant at their full value. The earthquake forces are assumed to be distributed along the height according to Ethiopian seismic code (ES EN 1998:2015). According to (Bourada Sofiane and Branci Taïeb, 2014) the lateral forces were increased in suitable increments until a mechanism forms, or an inter storey displacements goes past the design limit of 2% of the storey height. In the analysis it is assumed that the plastic hinges form only at the ends of the members. The moment-rotation relationship for a potential hinge is taken to be bilinear or elasto-plastic. The analysis includes an elastic and inelastic range. Inelastic range starts at the stage of first plastic hinge formation and ends when the mechanism is formed. The objective was to estimate the capacity curves, the over strength factors and the ductility factors.

5. Results of Pushover Analysis

The capacity curve (pushover curve), in terms of roof displacement-base shear, is shown in figure 1. this pushover curve is plotted until the displacement corresponding to the available capacity at near collapse limit state. In this study, analyses have been performed using ETABS 2016 Ultimate 16.2.1 computer program. Maximum base shear(yield shear) in actual behavior, V_y, base shear relevant to formation of first plastic hinge, V_1, over strength factor, Ω, ductility factor, μ, for all four structures under investigation are listed in Table 2 and 3 for EQx and EQy for x and y direction respectively. Displacement ductility is defined in terms of maximum structural drift and the displacement corresponding to the idealized yield strength. The behavior factor, q, is computed from ES EN 1998:2015 Table 3.2, for medium ductility class (DCM) as the 3.9, 3.12 ,3.12 ,3.12 for structure 1, 2, 3 and 4 respectively. Code gives constant value of behavior factor, q, for all structures. The over strength factor were found to be in the range of 0.63 to 1.02 in both x and y direction. Also, ductility factors for the structures found to be from 1.46 to 2.95 and 1.2 to 1.31 in both x and y direction respectively

Table 2. Yield shear, base shear at first plastic hinge, maximum roof displacement, yield displacement, over strength and ductility factor due to EQx

Model	V_y (KN)	V_1 (KN)	Δ_{max} (mm)	Δ_y (mm)	Ω	μ
Str 1	-	-	-	-	-	-
Str 2	219.29	311.8	6.606	4.531	1.02	1.46
Str 3	284.1	277.4	6.508	4.404	1.02	1.48
Str 4	112.03	178.8	9.455	3.201	0.63	2.95

Table 3. Yield shear, base shear at first plastic hinge, maximum roof displacement, yield displacement, over strength and ductility factor due to EQy.

Model	V_y (KN)	V_1 (KN)	Δ_{max} (mm)	Δ_y (mm)	Ω	μ
Str 1	-	-	-	-	-	-
Str 2	219	213	26.34	20.7	1.02	1.27
Str 3	196	200	27.22	21.31	1.02	1.27
Str 4	90	145	26.98	20.56	1.31	1.31

6. Discussion of Results

Based on the results obtained above, the following conclusions were drawn:

1. The over strength factor, Ω, decreases as vertical irregularity (non uniform profile) of the structures increase.
2. The structure with uniform profile (regular in elevation) has more lateral load capacity factor (over strength factor, Ω) compared to structures with non-uniform profile in elevation (or with setbacks). In other words, the structures with vertical geometric irregularity have lower demands than regular structure.
3. The ductility, μ, factor increases as vertical irregularity of the structures increases both in x and y
4. Structure 1 has shown neither yielding nor plastic hinge so structure1 with stands seismic failure due to its vertical regularity.

7. Conclusion

. Finally, the results obtained lead to the following main conclusion:

- The over strength factor decreases when vertical irregularity increases as a results of the decrease in storey shear of the structure in both x and y direction.
- The over strength factor decreases when vertical irregularity increases and results the increase in storey drift of the structure in both x and y direction.
- The ductility factor increases when vertical irregularity increases and results the increase in storey drift of the structure in both x and y direction.
- The storey shear also decreases when vertical irregularity increases which results a decrease in over strength factor in both x and y direction

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