

**A STUDY FOR FACTORS AFFECTING CURVATURE DUCTILITY IN CONCRETE SHEAR WALLS IN ACCORDANCE TO THE ARABIC CODE IN YEMEN****Abdulrahman Ali, Khalil Al-Bukhaiti*, Mohammed Al-Jaboob I, Khalid Zaidi**

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DOI: 10.5281/zenodo.1238624**KEYWORDS:** curvatures ductility - Regularly distributed reinforcement - Shear walls - Seismic loads.**ABSTRACT**

Securing ductility in earthquake –resistant construction systems is one of the main reasons that justify the need to lower forces caused by earthquakes in which these construction systems are built on. Shear walls are considered one of the most significant systems used to increase earthquake resistance for buildings. In this paper, I have analyzed a considerable number of factors that could affect curvature ductility of shear walls. Factors such as the distribution of reinforcement and percentage of reinforcement in both evenly distribution of reinforcement and concentrated in the ends.

Moreover, the regular load stress put on walls, the length of the wall in addition to the characteristics of the material used in construction. From the results of the paper it was found that with the increase of reinforcement percentage, ductility decreases in shear walls, which has systematic reinforcement. However, it stays stable in walls with concentrated reinforcement in the two ends of the wall. In terms of the effects of the stress caused by the regular load of construction, it was found curvature ductility decreases when the load is high. However, it becomes almost nonexistent when the regular load is more than half the maximum regular load permitted.

INTRODUCTION

Most reinforced concrete constructions in Yemen are designed based on shear walls for resisting earthquake loads; even though maximum cost resulting from the factor of decreasing the load is lower compared with other construction systems. For instance, Dual construction systems which consist of both shear walls and moment resistant frames or only moment resistant frames system. In most cases, shear walls are combined with systematic frames which are responsible for carrying axial loads only. Nevertheless, regular frames conditions are applied in relation to reinforcement details especially in the top ends of the construction components such as columns and bridges.

Considering the importance of shear walls in resisting seismic loads, it is important to study coefficient that affect its ductility. This is because ductility plays a crucial role in dissipation seismic stress on buildings and sustaining most construction resistance whether it is side or axial loads. Most shear walls also contribute in resisting axial loads in addition to its main task in resisting lateral loads.

In this paper an analysis study on factors related to shear walls ductility's was conducted by analyzing the relation between bending moment and curvature for shear walls then extracting Curvature Ductility.

The following factors would be considered in shear walls ductility: -

Effects of reinforcement percentage and distribution, Effects of regular loads, effects of construction material characteristics.

In order to establish the correlation line between Bending moment and Curvature in shear walls, we must determine the relation between compression stress and the strain in the reinforcement concrete. Additionally, the relation between compression stress and the reinforcing steel strain, All of which must be in accordance with regulatory engineering codes in this paper the American Code (UBC97) has been selected because it is a fundamental reference fir the Arab Code which is used in the designing methods in Yemen.



CONCRETE AND STEEL PROPERTIES

In terms of the relation between stress load and the reinforced concrete to achieve strain higher than ϵ_0 the correlation would make a straight line relation. For a strain smaller than ϵ_0 the relation would be represented in a vertical curve of the second degree, where ϵ_0 is given by the following equation:

$$\epsilon_0 = 2 \frac{f'_c}{E_c} \tag{1}$$

To achieve $\epsilon_0 > \epsilon$ concrete stress is given by the following equation:

$$\sigma = \left[2 \left(\frac{\epsilon}{\epsilon_0} \right) - \left(\frac{\epsilon}{\epsilon_0} \right)^2 \right] f'_c \tag{2}$$

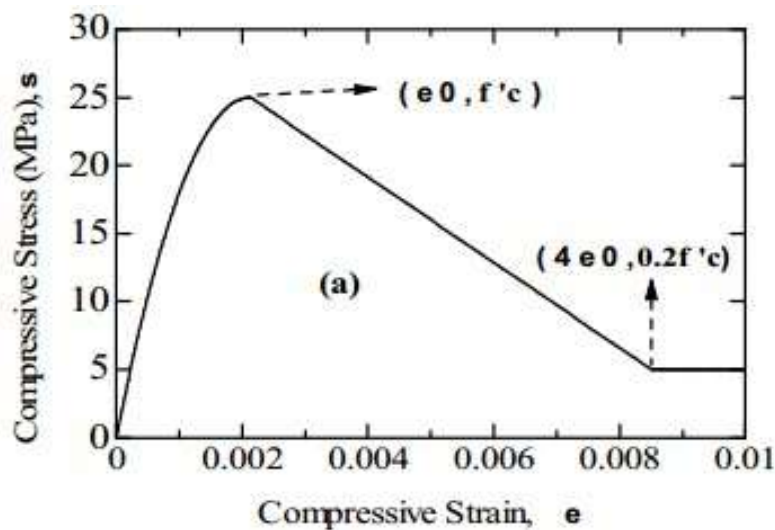
To achieve $\epsilon_0 > \epsilon$ the curve should be aligned with straight lines and σ is found by equation (2) with values as it follows:

$$\epsilon_0 = 0 ; \epsilon_0 = 0.2 ; \epsilon_0 = 0.4 ; \epsilon_0 = 0.6 ; \epsilon_0 = 0.8 ; \epsilon_0 = 0.9, \text{ and limit from } \epsilon_0 \text{ to } 4\epsilon_0$$

When observing the linear relationship where concrete resistance decreases from f'_c to $0.2f'_c$ then this resistance continues until it collapses with a strain $\epsilon = 10\epsilon_0$, when there is a strain effect the stress is zero. Relation between stress and strain in reinforcement steel is given using the same equation in correlation with stress of tension and compression. f_y is determined according the steel type. The relation between stress yield f_y and maximum stress (f_u) for steel by $f_u=1.25f_y$. Additionally, yield is measured by the equation (3) as in the following formula:

$$\epsilon_y = \frac{f_y}{E_s} \tag{3}$$

When steel resistance is equal to yielding stress until strain is $\epsilon = 0.002$. After that steel gets back some of its stiffness and its resistance increases until it reaches its maximum level f_u where $\epsilon = 0.0005$, resistance increases until $\epsilon = 0.0008$ then steel resistance decreases dramatically until it reaches the collapsing point and strain becomes $\epsilon = 0.01$.



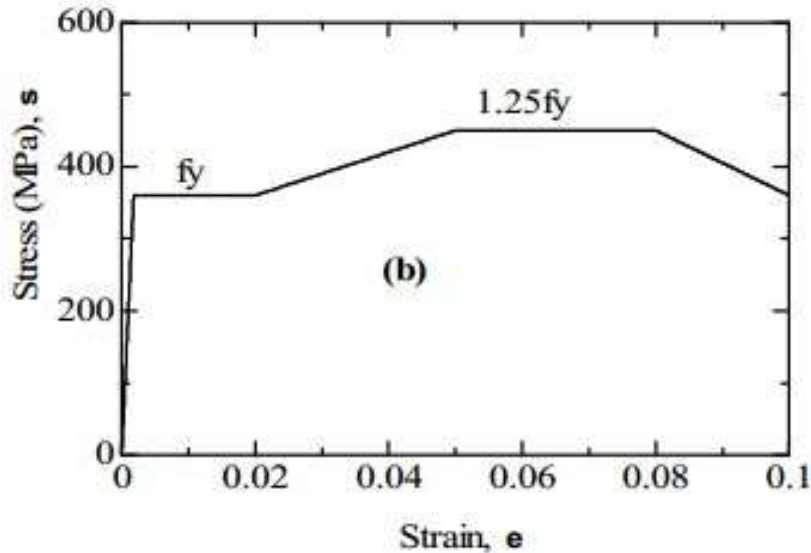


Figure (1) ϵ, σ relation for concrete (a) and steel (b)

Figure (1-a) shows the linear relation between compression and strain for concrete. This relation is shown for steel in diagram (1-b) from the above diagrams curves were extracted where: $f'_c = 25 \text{ MPa}$ $\therefore f_y = 360 \text{ MPa}$.

CALCULATING CURVATURE DUCTILITY FOR SHEAR WALLS

Curvature ductility of the shear wall (ϕ), is exposed for regular load and a bending moment equal to slope of strain line divided by the length of the section. If it was presumed that the greater concrete strain (ϵ_c) and the maximum strain in reinforcement steel (ϵ_s) and that the distance between the maximum compressed arm and the farthest position of the center reinforced tension bar is (d') we could calculate curvature of the shear wall (ϕ) using the following equation:

$$\phi = \frac{\epsilon_s + \epsilon_c}{d'} \quad (4)$$

Bending Moment curve is drawing for a specific regular load. The top point of the curve could be a predetermined number; in this paper (11) point was chosen for every curve. In addition, the point of maximum curve should stop should be chosen, and it could be presumed equal to the curve point where the reinforcement bar failures where the distance between the rod and the centre of the section load is (y). Presuming that (ϕ_f) is the failures point for the bar, and ($(\epsilon_s)_f$) is the failure strain for the reinforcement bar, then (ϕ_f) is measured by the following equation:

$$\phi_f = \frac{(\epsilon_s)_f}{y} \quad (5)$$

The reinforcement bar which are the most distanced from load centre were chosen so we can get the smallest value for failure point of the curve. As it can be seen in figure (2) a perfect example of the correlation between bending moment and the curvatures. Usually, bending moment and curvature is rounded to bilinear, presuming M_y bending moment at the yielding point, and ϕ_y is yielding curve, ϕ_m is the maximum curve where it is possible to obtain the closest result for the real curve compared to the bilinear, then curvature ductility could be found by the following equation:



$$\mu_\phi = \frac{\phi_m}{\phi_y} \quad (6)$$

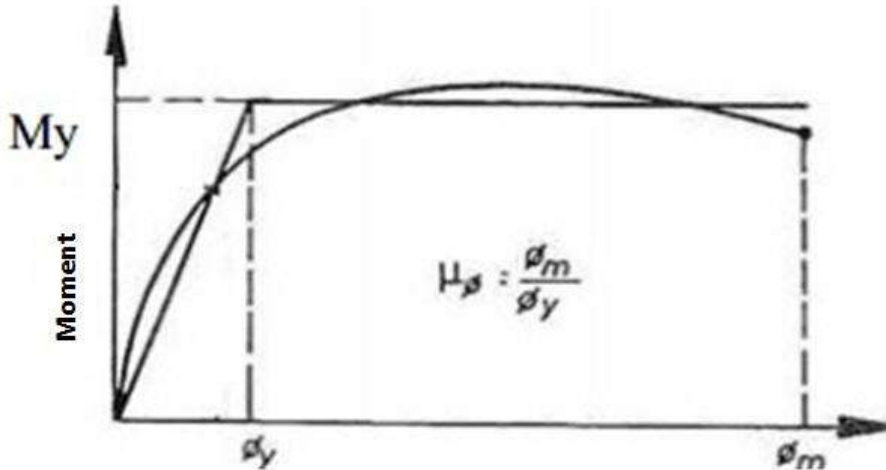


Figure (2) showing (μ_ϕ) formula.

REINFORCING THE SHEAR OF WALLS IN THE ARABIC CODE

Figure (3) shows how to choose the method of reinforce the shear walls according to the Arabic code, calculates the eccentricity that is exposed to the wall (e), and compares with the equilibrium eccentricity (e_b). If (e) is less than (e_b) is considered a small value, and If (e) greater than (e_b) is considered a significant value. If the eccentricity is small, the two cases can be distinguished as follows:

- 1) The pressure strength in the case of the maximum in the critical section of the shear wall does not exceed half the maximum resistance in the pressure of this wall. In this case, there is no need for the placement of hidden columns at the ends of the walls. In this case, the uniform reinforcement wall shall be uniformed and the minimum reinforcement ratio (0.2%) for high-resistance steel, When the maximum limit resistance exposed to the wall (N_u) on the half of the maximum regulatory force ($N_u \max$) allowed to apply to the wall calculated from the following equation:

$$(N_u)_{max} = 0.8\Omega[0.85f'_c(Ag - As) + f_y] \quad (7)$$

Where:

(Ω) = The pressure reduction factor

(Ag) = Total area of concrete section and the

(As) = area of the reinforcement bars section.

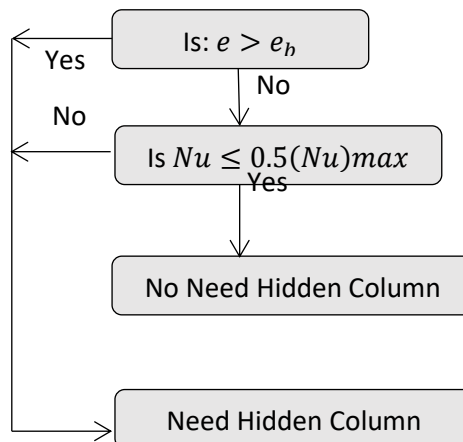




Figure (3) shows the need for hidden columns in the shear walls according to the Arabic code

This minimum ratio is increased linearly up to (0.6%) of the actual wall section when the maximum limit force exposed to the wall reaches the maximum force ((Nu) max), in cases where the wall is subject to small eccentricity compression pressure in the case of maximum.

- 2) In the case of the maximum pressure in the critical section half of the maximum pressure resistance of this wall is exceeded. In this case, hidden columns at the end of the wall are placed in thickness (t) and the length of the section is (2t) at a minimum and maximum length (0.2L) the length of the wall is used for ratio of longitudinal reinforcement (1-1.5%). If the shear wall in the case of the max is exposed to a large eccentricity compression pressure, the necessary reinforcement of the tensile strength shall be calculated and concentrated in a hidden column according to the dimensions and reinforce requirements mentioned above.

EFFECT OF THE RATIO OF REINFORCED AND DISTRIBUTION

In order to study the effect of the ratio of the Reinforced and its distribution in the shear walls on the ductility, the two cases of regular Reinforced and central Reinforced were studied at the ends with a structural Reinforced between them. The concrete resistance was selected on pressure ($f'_c = 25 \text{ MPa}$), and steel was also selected for Stress of yielding $f_y = 360 \text{ MPa}$, the coefficient of elasticity of concrete is calculated from the relationship $E_c = 4700\sqrt{f'_c}$. Where E_c and f'_c is in unit (MPa), The coefficient of elasticity for steel was adopted $E_s = 2 \times 10^5 \text{ MPa}$, and a Shear wall with length (3 m) and thickness (0.3 m) and using the first case as a regular reinforced, Where the curves of the relation between the bending moment and curvatures were drawn into several reinforcements: (0.2% ; 0.4% ; 0.6% ; 0.8% ; 1.0% ; 1.5%) the applied regulatory force was zero. Figure (4) shows these curves for the state of regular reinforced, as summarized in Table (1) calculate the ductility of the various ratios of reinforcement.

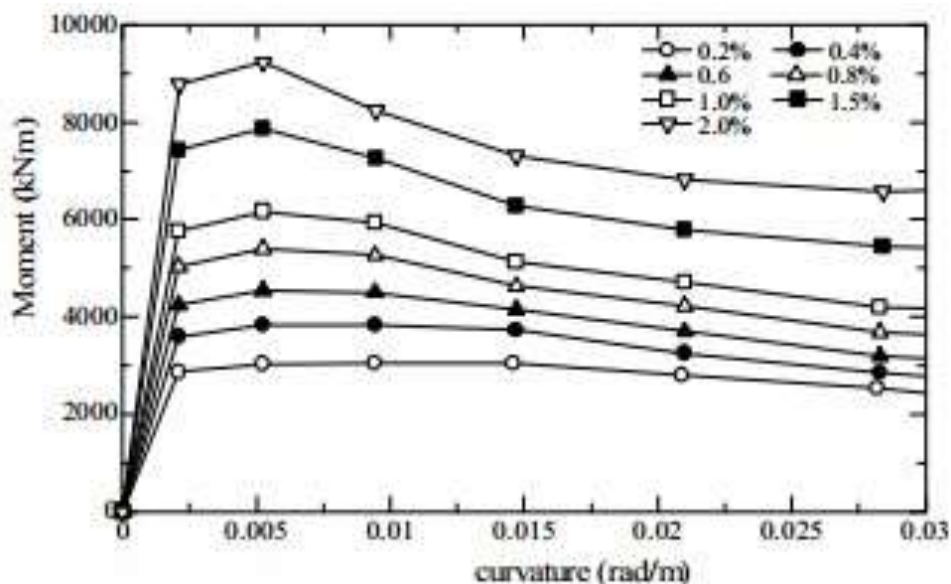


Figure (4) Curves of bending moment - curvatures, in a regular reinforced

It is noted from Figure (4) and Table (1) that with the increase in the percentage of reinforced decrease curvature ductility. It is also noted that the rate of reduction of resistance increases after the arrival of resistor moment to its maximum value with increasing ratio of the reinforcement.



Table (1) Ductility values in case of regular reinforced

Case No.	Reinforcement Ratio %	Phi-y	Phi-u	ductility
1	0.2	0.00209	0.01907	9.1
2	0.4	0.00209	0.01628	7.8
3	0.6	0.00209	0.01348	6.4
4	0.8	0.00209	0.01167	5.6
5	1.0	0.00209	0.01069	5.1
6	1.5	0.00209	0.00883	4.2
7	2.0	0.00209	0.00696	3.3

The status of central reinforcement was also studied at the ends (hidden columns), and the shear walls were examined with four cases of ratio of reinforcement in the hidden columns (1.0%; 1.5%; 2.0%; 2.5%), While a minimum reinforcement with value of (0.2%) was placed in the area between the hidden columns of all cases. and a regulatory load of 10% of the maximum allowable load has been applied.

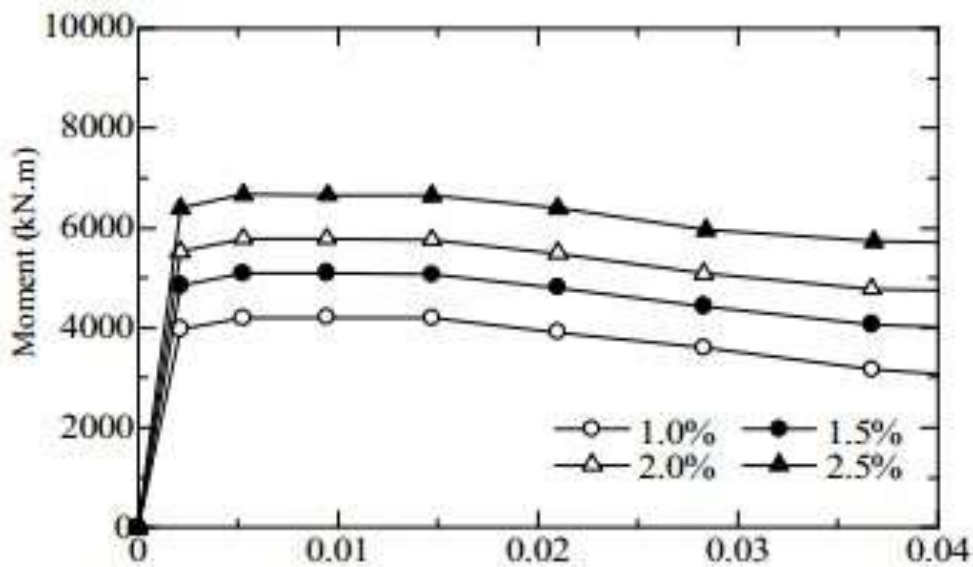


Figure (5) Relationship of moment to curvatures - center reinforcement at the ends

It is noted from Figure (5) that the ductility remained almost constant for all reinforced ratios and is (4.5), and the resistance decreases at a lower rate in the case of central reinforced compared to regular reinforcement.

Because we want to study the effect of changing the dimensions of the hidden column in the curve of the relation between the bending moment and curvature and then ductility, the case of shear walls length (6 m), thickness (0.3 m) and four cases of change of hidden column length (1.2; 1.0; 0.8; 0.6 m) The columns were reinforced with a ratio of (1%) and the part between the two hidden columns (0.2%). The wall was loaded with a distribution load of 10% of the maximum load that it could carry in each case. Figure (6) shows the curves in the four cases. It is noticeable from the figure that the ductility bending values have not changed nearly equal to (10), but the collapse of the resistance is greater than the case in which the dimensions of the hidden column are maintained and the proportion of reinforcement is increased.

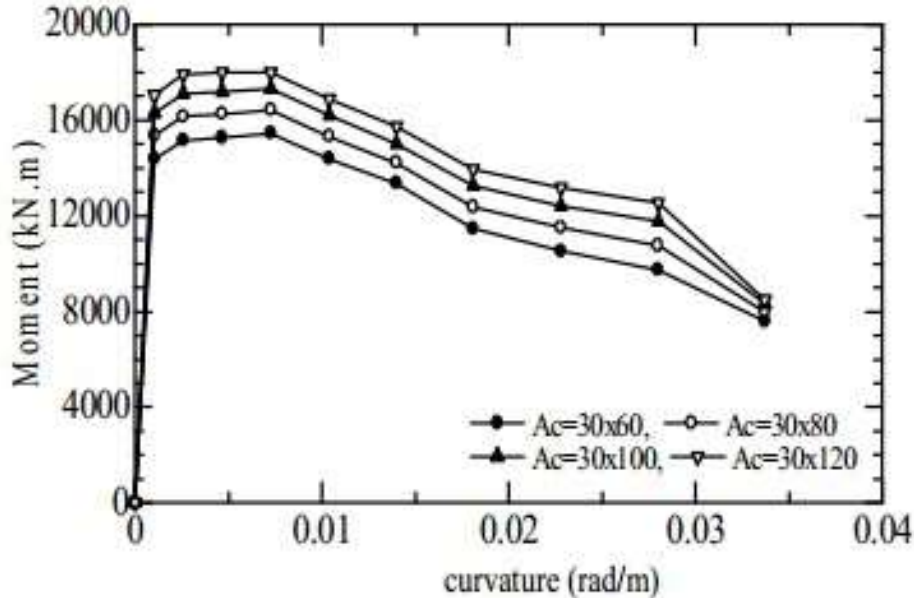


Figure (6) curvatures - moment for Variable hidden column dimensions

EFFECT OF THE INTENSITY OF DISTRIBUTION LOADS

The effect of the intensity of the regular loads in the ductility of the shear walls was studied through the study of shear wall sections of length (3.0 m) and thickness (0.3 m), regular reinforced has been done at the rate of a diameter bar (12 mm) each (25 cm) on both sides of the wall, (r) is the ratio between the maximum limit force exposed to the wall (Nu) and the maximum regulatory force (Nu max) allowed to be applied to the wall, where the curves of the moment relationship were calculated and bent for the values of (r) equal to (0; 0.1; 0.2; 0.35; 0.5). Figure (6) shows the relation of the bending moment to the curvature indicated ratios.

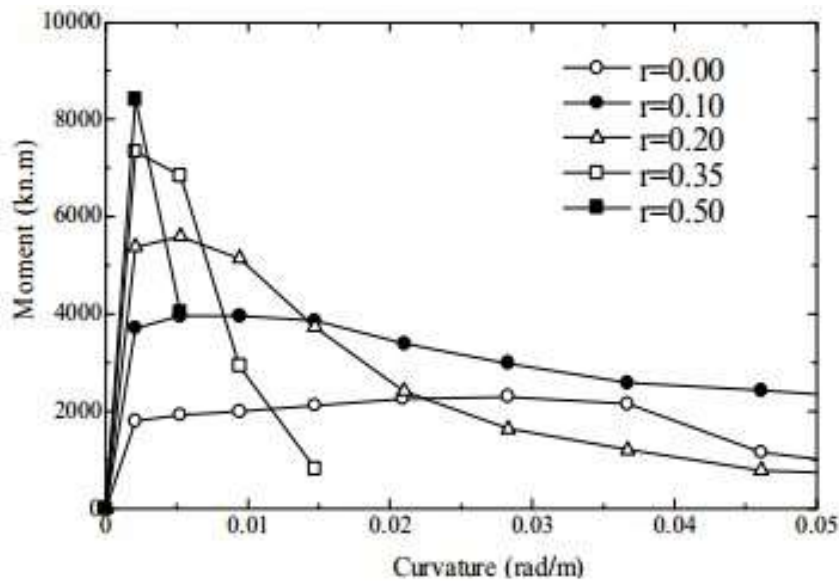


Figure.7 shows the relationship of moment to curvature - regular reinforced



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From Figure (7), the values for Table (2) were found to calculate the bending ductility at each value of factor (r), this table shows that the ductility decreases rapidly with the increase in the value of (r), and we may not get any ductility when the ratio reaches (r = 0.5).

Table (2) shows the bending ductility values - the effect of the regulatory loads

r	Phi-1	Phi-2	ductility	Strength (KN.m)
0	0.0021	0.0367	17.5	1800.0
0.1	0.0021	0.0147	7.0	3716.0
0.2	0.0021	0.0094	4.5	5386.0
0.35	0.0021	0.0052	2.5	7348.0
0.5	0.0021	-	-	8418.0

It can be said that the Arabic code does not allow (r) access to this value as long as the wall resists seismic load, otherwise it must be neglected to resist these loads.

EFFECT OF CHANGING WALLS LENGTH

In order to study the effect of the length of the wall in the ductility, three walls were studied in the longest (3 m, 5 m, 7 m). A hidden column was placed at each end of each wall (30x60 cm) with a percentage of reinforce (1%), while the lower reinforce was placed in the area between the two hidden columns, where the ratio of reinforce (0.2%). All cases were calculated for (r = 0.1). Figure (8) shows the curves of the moment - curvatures of the walls mentioned, as summarized in Table (3) curvatures values at yielding and the values of maximum curvatures and ductility of each case.

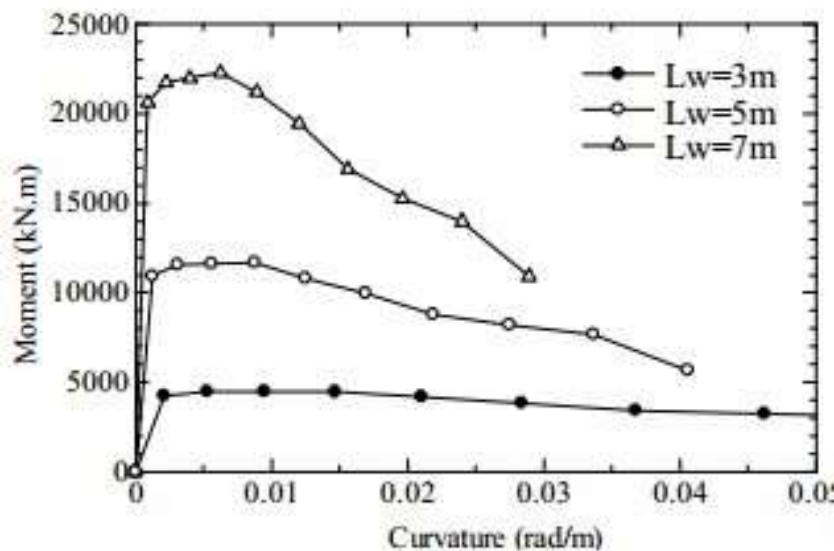


Figure (8) shows the relationship of moment to curvature - different lengths of walls

Figure (8) and Table (3) show that the ductility decreases value with the length of the shear walls, as well as a greater rate of decrease of resistive moment with increased wall length.

Table (3) show that the ductility decreases value with the length of the shear walls

Case No.	Lw (m)	Phi-y	Phi-u	ductility
1	3	0.0021	0.021	10
2	5	0.0021	0.0125	6.0
3	7	0.0021	0.0089	4.2

**EFFECT OF MATERIAL PROPERTIES**

In this section we study the effect of material properties on the ductility curvature of the shear walls, the stress of yielding in f_y , the concrete resistance of the pressure on f'_c , and for the concrete resistance to pressure, the values (20; 22; 25 MPa) and the stress of yielding for steel, the values were selected (300; 360; 400 MPa). The walls of their sections were selected with thickness (30 cm) and length (300 cm). The whole cases were calculated for ($r = 0.1$). Figure (9a) shows the relation of moment-curvature in two cases, as follows:

- 1- Regular reinforcement on the whole wall ($\emptyset 12 / 25\text{cm}$) is a set of curves (1).
- 2- Regular reinforcement ($\emptyset 10 / 25\text{cm}$) with hidden columns achieving minimum dimensions and reinforce ($6\emptyset 20$), a set of curves (2).

The curvature of the ductility of the curves was about (10), no significant change was observed in the curvature ductility when the stress of yielding for steel was changed within the range of selected values, note that resistance of moment is clearly increasing.

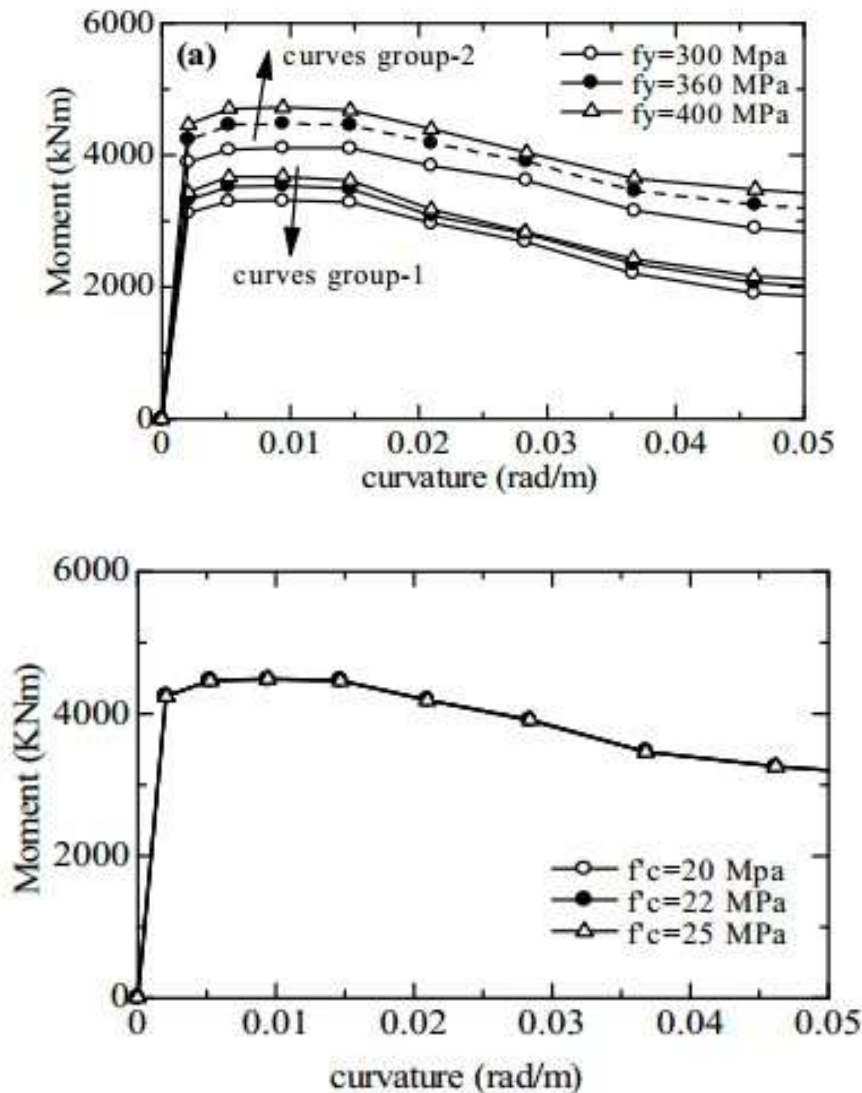


Figure (9-a) shows the effect of changing the value of (f_y)
(9-b) shows the effect of changing the value of (f'_c)



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Figure (9-b) shows the relationship of the bending moment with curvatures with the constant of (f_y) and the change of (f'_c). The elasticity modulus for each case has been changed according to the relationship in part (5), and we observe here the almost complete applies of the three curves. This indicates that changing the value (f'_c) within the range of the selected values does not give an effect either in the curvatures ductility or resistant moment. The curvature of the ductility was about (8.5).

CONCLUSIONS AND RECOMMENDATIONS

Some factors related to the curvature of the ductility in the shear walls were studied in this paper by calculating and plotting curves that represent the relation between the bending moment and curvatures of the sections of these walls and thus calculating the curvature of the ductility, the paper findings and recommendations can be summarized as follows:

- 1) With increased regulatory strength applied to shear walls less than their ductility, and is almost absent when shear walls are subjected to a regulatory pressure of up to 50% of the maximum regulatory force allowed to be applied to the wall.
- 2) In the sections of the shear walls with regular reinforcement, the ductility shall be reduced with increasing ratio of reinforcement.
- 3) In the sections of the shear walls with the hidden columns, the ductility remains stable with the increase of the reinforcing ratio in these columns.
- 4) The ductility is clearly reduced as the length of the shear walls increases, so it is preferable to use short multiple walls in each of the two main directions of construction where possible.
- 5) It is recommended to review the permissible regulatory force applied to the shear walls that contribute to the resistance of seismic loads in the Arabic code, and not to allow a regulatory force to make the ductility of the walls unacceptably low.
- 6) It is also recommended to study the factors that affect the ductility rotation and the transition of shear walls.

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