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Optimal position of outriggers for minimizing the base moment under lateral load

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ABSTRACT: In this paper, the optimum position of Outriggers in a structure for minimizing the base moment under lateral loads is investigated. To do so, the base moment and top story displacement are formulated. Then, a Matlab code is employed to find the optimum positions of the Outriggers. Different kinds of lateral loads including concentrated, uniform, triangular and a combination of such loads are taken into account. Moreover, the effects of the variation of structural elements such as columns, Outriggers and core on the base moment and top story displacement are examined. The outcomes indicated that the optimum points of Outriggers get closer when the flexural rigidity of Outriggers increases. Furthermore, it is shown that the greatest decrease in the base moment occurs in a specific range which depends on the structure parameters such as axial rigidity of columns, the distance of columns, the flexural rigidity of Outriggers and height of the structure. The results show that when the wind load intensity increases, the optimum position of the Outriggers will move to the top of the structure.

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1- Introduction

Controlling the top story displacement and the maximum moment at the core of structures are two of the major issues in the design of tall buildings. Outrigger system is one of the most effective approaches to increase the stiffness of high-rise structures. The use of outriggers system to reduce the displacement created on top of tall structures back to four decades ago [1]. Shivacharan et al. [2] investigated the optimal location of the outriggers for structures with irregular heights in order to minimize the maximum displacement of the structure. Kamgar and Rahgozar [3] investigated the optimal location of the outriggers based on the energy method. Gunda and Anthugari [4] investigated the effect of ourtriggers and core flexural rigidity on the optimal location of outriggers. They considered 4 ratios of outriggers flexural rigidity to the core to obtain the optimal condition.

In this research, the optimal location of the outriggers in the structure has been investigated to obtain the minimum base moment in the core.

2- Structural analysis

The assumptions used to analysis the structure in this research are as follows.

The behavior of the structure is elastic.

Only axial force is considered on the columns.

The outriggers are rigidly attached to the core and joint to the column.

The geometric properties of the core, columns and outriggers are considered uniform in the height of the structure.

An overview of the structure with two outrigger and distribution the lateral wind loading is shown in Figure 2.

Rotations of the core at elevations 1 and 2 can be derived from next relations.

$$\theta_1 = \frac{1}{EI}\int_{x_1}^{x_2}\left(\left(\frac{w}{(\beta+1)(\beta+2)}(H-x)^{\beta+2}dx + H^{\beta+1}(x(\beta+2)-H)\right)-M_1\right)dx + + \frac{1}{EI}\int_{x_2}^{H}\left(\frac{w}{(\beta+1)(\beta+2)}(H-x)^{\beta+2} + H^{\beta+1}(x(\beta+2)-H)\right)-M_1-M_2)dx \qquad (1)$$

$$\theta_2 = \frac{1}{EI}\int_{x_2}^{H}\left(\frac{w}{(\beta+1)(\beta+2)}(H-x)^{\beta+2} + H^{\beta+1}(x(\beta+2)-H)\right)-M_1-M_2)dx \qquad (2)$$

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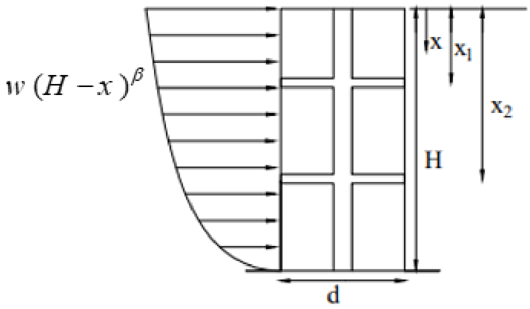

Fig. 1. Structure with two-outrigger system under wind loading

in which *EI* is flexural rigidity of the core.

The outriggers rotations at the connections to the core can be derived from next relations.

$$\theta_1=\frac{2M_1(H-x_1)}{d^2(EA)_C}+\frac{2M_2(H-x_2)}{d^2(EA)_C}+\frac{M_1 d}{12(EI)_o} \qquad (3)$$

$$\theta_2=\frac{2(M_1+M_2)(H-x_1)}{d^2(EA)_C}+\frac{M_1 d}{12(EI)_o} \qquad (4)$$

Where $(EI)_o$ and $(EA)_c$ are the flexural rigidity of the outrigger and the column, respectively. The compatibility of deformations is imposed by setting rotations of the core equal to those of the outriggers. After equating the relationship 1 with 3 and 2 with 4 and simplification:

$$\begin{bmatrix} M_1 \\ M_2 \end{bmatrix}=\frac{w}{EIH}A_1^{-1}B_1\,,$$

$$A_1=\begin{bmatrix} S_1+S(H-x_1) & S(H-x_2) \\ S(H-x_2) & S_1+S(H-x_2) \end{bmatrix}$$

$$B_1=\begin{bmatrix} \dfrac{H^{\beta+1}\beta(H^2-x_1^2)+2H^{\beta+1}x_1(H-x_1)}{2(\beta+2)(\beta+3)}+ \\ \dfrac{(H^2-2Hx_1+x_1^2)(H-x_1)^{\beta+1}}{(\beta+1)(\beta+2)(\beta+3)} \\ \dfrac{H^{\beta+1}\beta(H^2-x_2^2)+2H^{\beta+1}x_2(H-x_2)}{2(\beta+2)(\beta+3)}+ \\ \dfrac{(H^2-2Hx_2+x_2^2)(H-x_2)^{\beta+1}}{(\beta+1)(\beta+2)(\beta+3)} \end{bmatrix} \qquad (5)$$

Where S and S1 can be computed through the use of the next relation:

$$S=\frac{1}{EI}+\frac{2}{d^2(EA)_C}\;,\; S_1=\frac{d}{12(EI)_o} \qquad (6)$$

The core base moment according to the wind loading is obtained from Equation (7).

$$M_e=\frac{wH^{\beta+1}}{\beta+2}-M_1-M_2 \qquad (7)$$

The optimum locations of the outriggers are determined by minimizing the base moment. One can minimize this parameter by maximizing the second term in the right-hand side of Equation (7). This is done by setting its derivative with respect to outrigger location variable equal to zero. Therefore, the following system of equations will be in hand:

$$\begin{aligned} &\frac{\partial}{\partial x_1}\left(\frac{w}{EIH}B_2^T\,(A_2^{-1})^T e^T\right)=0 \\ &\frac{\partial}{\partial x_2}\left(\frac{w}{EIH}B_2^T\,(A_2^{-1})^T e^T\right)=0 \end{aligned} \qquad (8)$$

The maximum reduction ratios of moment, Will be obtained using the following equation:

$$E_M=\frac{\dfrac{w}{EIH}B_2^T\,(A_2^{-1})^T e^T}{\dfrac{wH^{\beta+1}}{(\beta+2)EIS}}=\frac{S(\beta+2)}{H^{\beta+2}}B_2^T\,(A_2^{-1})^T e^T \qquad (9)$$

3- Results and Discussion

In this study, the number of arm restraints in the structure is 4. To consider all members of the structure, dimensionless parameters of relation (10) are defined.

$$\omega=\frac{\gamma}{12(1+\lambda)},\;\; \lambda=\frac{EI}{(EA)_C\,(\frac{d^2}{2})},\;\; \gamma=\frac{EId}{(EI)_o H} \qquad (10)$$

λ Indicates the ratio of core flexural rigidity to column rigidity and γ Indicates the ratio of core flexural rigidity to outrigger flexural rigidity**.**Figure 2 demonstrates the variation of the optimum location with respect to ω in a structure under wind loading.Figure 3 shows the variation of moment reduction factor with ω.

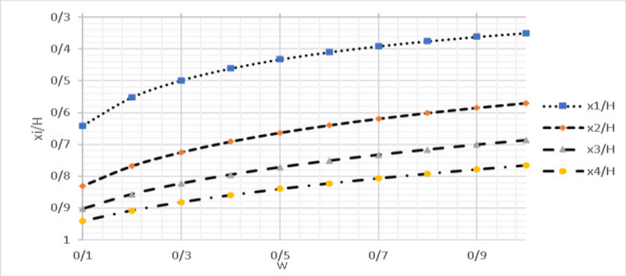

Fig. 2. Optimum locations of the outriggers in a four-outrigger system under wind loading (β=0.14)

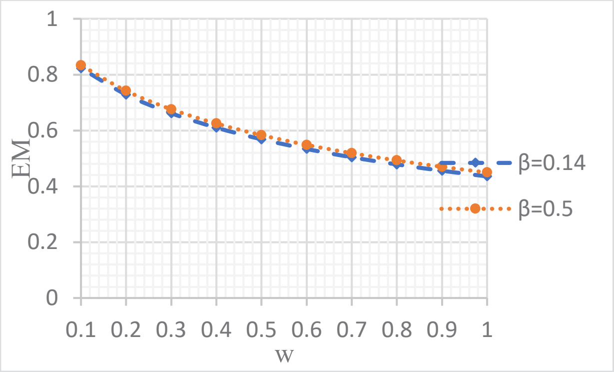

Fig. 3. moment reduction ratio in a four-outrigger system under uniform loading

4- Conclusions

The results showed that as the flexural rigidity of the outriggers increase, the optimal location of the outriggers will shift to the bottom of the structure. Also, as the flexural rigidity of the outriggers increases, the distance between the outriggers will decrease. With increasing flexural rigidity of the outriggers, maximum reduction ratios of moment increase compared to the case where there is no outrigger in the structure, which can increase the efficiency up to 85%. As the wind load increases, the optimal location of the outriggers will move to the top of the structure.

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