Methodology for Optimal Diagrid Angle Evaluation

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Abstract — In recent years, diagrid has emerged as an effective structural system for high rise structures. The design of diagrid structure consist of many variable parameters. The efficiency of the diagrid structure hence depends on the optimizing these parameters. In this study two effective methodology are discussed, statistical method and gradient method. The statistical approach requires a window of value of s (ratio of displacement contribution due to bending to contribution by shear), whereas the gradient method is more flexible as it does not require any prior prediction of range of values. The gradient method is also capable of optimizing multiple parameters in few iterations.

Index Terms— Diagrid, Diagonal angle, Gradient descent, Optimization.

I. INTRODUCTION

Diagrid is a steel structural configuration for tall building. The columns are inclined in these structures hence they are known as diagonal and form grid around structure. Hence, the structure are known as 'Diagrid' structure. The diagrid is known for its efficiency in terms of lateral displacement and stiffness. Considerable work and research has been done to prove the efficiency of the diagrid structure. The efficiency of the diagrid structure depends on various parameters such as module height, diagonal angle, storey height, etc. Out of these, angle of diagonal affects the efficiency of diagrid structure considerably. Hence, to find the optimal angle of diagrid is an important task. There are various methods available in literature to find the optimal angle, but they are dependent on specific parameter optimization rather than optimizing the most of parameters into consideration. Hence, the present paper provides and explores some sophisticated methods to find the optimal angle of the diagrid structure for maximum efficiency. The goal of each optimization is to attain minimum weight for maximum lateral stiffness or for minimum lateral displacement within the limits prescribed by the regional codes.

II. METHODOLOGIES

i. Statistical Method:

This method can be categorized broadly as manual method as the calculation of weight of diagrid is necessary at each step to plot the graph to find the minimum weight of diagrid structure. The process starts by defining the required parameters such as shear force, bending moment at storey, module height, building height, width of building, etc. The side of building where the lateral forces are acting is termed as web side of the building and the other side is known as flange of the building. The areas required for the shear force and bending moment for web and flange side of the building are calculated respectively using equation (1).

$$A_{d,w} = \frac{VL_d}{2N_{d,w}E_d h\gamma \quad cos^2\theta} \wedge A_{d,f} = \frac{2ML_d}{\left(N_{d,f} + \delta\right)B^2 E_d \beta \quad hsin^2\theta} \, (1)$$

Where, $A_{d,w}$, $A_{d,f}$: Cross sectional area on web and flange side respectively
V : Storey Shear, E_d : Modulus of Elasticity of diagonal member
M : Storey Moment, L_d : Length of diagonal member
H : Building height, $\gamma \wedge \beta$: Transverse and bending deformation desired
h : Module height, θ : Diagrid angle
$N_{d,w}$, $N_{d,f}$: Number of diagonals on web and flange side respectively.

The above equation requires the parameters γ and β which are displacement contribution due to bending and shear respectively. The parameters are interrelated and the relation between those is rather complicated. However, the ratio of displacement contribution of diagrid structure due to bending to that of the shear is termed as 's'. Then it becomes easier to express the parameters γ and β in terms of s. The only unknown parameter is the s itself and hence it is actually the step of diagrid. The weight of diagrid is calculated for each step i.e. for each value of s. The value if s is not necessarily depends on experience of designer but with experience one can accurately guess the window of parameter s. In taller buildings, bending governs the design. Hence the value of s is higher compared to shorter buildings where shear governs the design.

Even if it is specified in various literature that the best angle for diagrid is 67°, it is dependent on the geometry of the plan and storey height. Some plan geometry and height may not allow for particular angles like 67° to be physically applicable in structural aspect. The choices are narrower with respect to the physical dimensions of the building. Hence, the optimal angle for each building is different. However, for preliminary approach, angles closer to 67° can be considered for calculating sectional sizes of diagrid members. Lastly, the weight can be calculated as one would know the lengths of diagonal members and the density of the material used. The cross sectional area shall be larger of the $A_{d,w}$ and $A_{d,f}$ so as to satisfy minimum criteria. Then finally, graph of weight of diagrid periphery and parameter s is plotted, which will indicate the optimal weight and optimal s; corresponding which the angle of diagonal member is chosen. A typical graph is shown in figure 1. It shall be noted that this process is for given n-storey module. The same process shall be repeated for modules of different storey levels. Finally, the plots of each module heights are superimposed and the one with lowest weight shall be selected as the optimal angle of the diagrid structure.

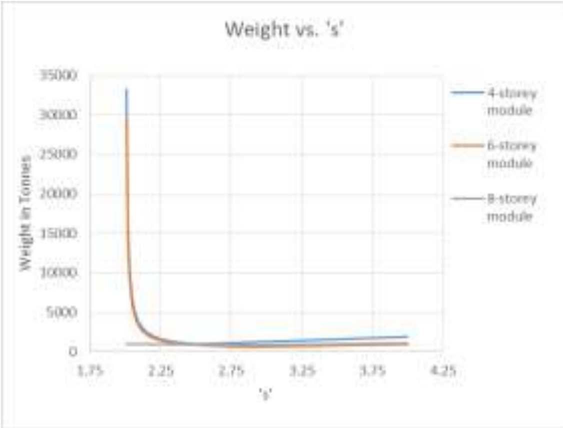

Figure 1: Superimposed graphs of different storey module, plotted with Weight of diagrids vs. 's'

ii. Gradient Method

Gradient is a mathematical technique to find the ascending part of the curve. The general equation for the same is given below:

$$\theta_j \underset{\leftarrow}{convergance} \theta_j - \frac{\partial}{\partial \theta_j} J(\theta) (2)$$

Gradient thus gives the direction in which one should proceed in order to find the maxima. Conversely, the negative of gradient will give you the minima. This is also known as Gradient Descent. However, this method only can find the local minima, but it is useful in our case as the curve of graph plotted between s and weight of diagrid shell has only one minima. Gradient descent method is superior to statistical approach as gradient reduces the number of computations required.
The gradient descent method comprises of the following steps:

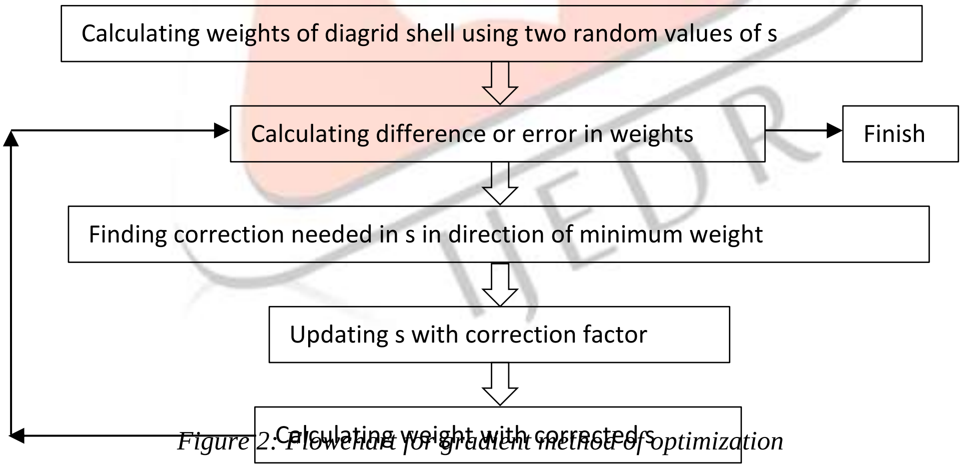

Figure 2: Flowchart for gradient method of optimization

Rearranging the equations of section calculation on flange and web side of building directly in terms of s, we get the following equation:

$$A_d = max \begin{Bmatrix} P(1+s) \\ Q(1+s) \end{Bmatrix} (3)$$

Where,

$$P = \frac{250VL_d}{N_d E_d h cos^2\theta} \wedge Q = \frac{500ML_d H}{(N_d+2)B^2 h sin^2\theta} (4)$$

The weight is calculated by using the length of diagonals and the known density of the material used for the diagonal members.

$$W = L \times \rho \times A_d (5)$$

Following the flowchart above, the first step is to calculate two weights for random values of s. The difference in the weight of diagrid is the error in direction towards the minimum weight.

$$e = \frac{1}{2}\sum\left(W_{upper} - W_{lower}\right)^2 \text{ (6)}$$

In order to find the actual error direction, the slope of above equation is obtained by using the partial derivative of above equation with respect to s.

$$\frac{\partial e}{\partial s} = -\left[L \times \rho\left\{[max(P,Q)]_{upper} - [max(P,Q)]_{lower}\right\}\right](7)$$

Since, we have direction towards the minima, we need amount by which the s should deflect. The value of s is calculated as-

$$s_{corrected} = s - r \times \frac{\partial e}{\partial s} \text{ (8)}$$

Finally, the weights are recalculated of the value of this corrected s termed as $s_{corrected.}$ The process is repeated until the error minimizes or converges. It should be noted that in above steps we have assumed that the parameter except s are constant. So this process has to be repeated for each value of other parameters if they are changing. Thus, for different angles of the diagrid, the optimal value of s needs to be calculated and then superimposed for the overall optimal value of angle and s. However, the variation in other parameters can be integrated in above equation by same approach as of the weight. Firstly, the error in variable parameter is calculated using similar equation as equation (6), followed by the amount of error by that parameter using partial derivatives and then correcting it. It can also be done by applying chain rule in the derivation step or in equation (7). The advantage of this gradient method is that it is not required to know the window of probable optimal values of s.

III. CONCLUSION

The optimal criteria of the diagrid structure is the weight of structure, as the weight optimization indirectly associates with the leaser consumption of material. The statistical method and gradient methods both provides the optimal solution for the problem. However, gradient method can be adjusted to suit for variation in other parameters as well by mathematical process. The same can be done in statistical method but needs to calculate preliminary data for the parameters. N statistical method, computational efforts can only be minimized if one is experienced enough to predict the values of parameters s. Gradient method can be provided with set of values for storey shear and moment to provide optimum solution at every module level, which would result in even more economic approach of diagrid design.

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