11 WCEE

Paper No. 634. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SEISMIC DESIGN DIRECTIONS OF STRUCTURES WITH BEAM YIELDING TYPE

MASAOMI TESHIGAWARA

Senior Research Engineer of Earthquake Engineering
International Institute of Seismology and Earthquake Engineering,
Building Research Institute, Ministry of Construction, Japan

ABSTRACT

The safety of a building should be examined for earthquake forces in all directions. In a building with two-way frame system, shear force, bending moment, and axial force acting on the column are larger in the off-frame direction than in the frame direction at the same drift. Force amplification factor to get the forces in the off-frame direction from those in the frame direction for a fully ductile frame, 1.4 for shear force and bending moment and 2.0 for axial force of corner column, are too large for a building, such as a high-rise building whose response is expected to remain within small inelastic ranges. This paper discusses and presents an evaluation method on the off-frame direction and on the force amplification factor for reasonable seismic design of buildings.

KEYWORDS

seismic design; earthquake motion; design direction considered; design deflection; beam yielding type; design in 45 degrees direction.

INTRODUCTION

Recently research on seismic design loads, discussions over earthquake mechanism, and the return period, effect of the distance between the building site and the epicenter have been progressed, and the response spectrum for seismic design has been able to be proposed. And structural performance has also been able to be evaluated precisely by a computer analysis and by precise evaluations on seismic performance of structural members. In Japan, however, a seismic design or a seismic check of a building is seemed to be conducted against specific seismic design loads only in the frame directions except for the building that has a special feature in the frame direction, in spite of the truth that the safety of buildings should be examined for earthquake forces in all directions. In this paper, the frame direction of the building with the two-way moment-resisting frame system is defined as the direction in which columns and beams are rigidly connected in a plane and consist of moment-resisting frame.

The missing of the design in arbitrary directions would be caused by the influence of the allowable stress design that was the leading seismic design method in Japan until 1981. In this design method working stresses of all structural members remain within their allowable stresses. In other words, almost all structural members behave their elastic manner against design forces. So that in the allowable design method, the seismic design of column shears, bending moments in the both frame directions can cover the design of those against the seismic forces in all directions as far as the yield surface of a column is an ellipse. The axial force on the column in the off frame direction loading, however, becomes larger than that in the frame direction. This is because the seismic design of the building is usually conducted in only frame directions except for the check on axial forces of column.

In the design method that allows the yielding of members and considers an elasto–plastic vibration feature of the building, however, the actions in columns produced by seismic responses in the off–frame direction are usually higher than that in the frame direction due to the effect of two–way moment–resisting frame system. The design force of columns depends on the load–deflection characteristics including hysteresis character of members whose responses are over their yield points. For example, seismic design code of New Zealand(1982) provides the design method of the full–ductile frame with beam yielding failure mechanism. The column in two–way fully ductile frames should be designed taking account that the beam or the brace in each frame direction yields in the flexure at the same time. Basically the effect of simultaneous flexural yielding of beams of each frame direction on the column shear, bending moment should amplify the forces of column in the frame direction by 1.4 times. As far as the fully ductile frame in N.Z.(1982) deflects into large inelastic ranges, amplifying force factor of 1.4 for column design will be reasonable. And many researchers in Japan also have pointed out the same design concept. For example, Prof. Kato (1983) reported that the reason why the building designed in beam yield mechanism type failed in column yield mechanism is that the force from beams in the diagonal directional loading became 1.4 times larger than in the frame directional loading. This fact indicates that the building which is designed in beam yield mechanism type considering in the frame direction only, has a probability of failing in brittle mode of columns if the beams would yield at the same time in 45–degrees directional loading.

The design force of the column has been discussed so far in the case that the beams connected with the column from both frame directions yield at the same time in the off–frame directional loading. On the other hand, the lateral load carrying capacity in the diagonal direction is usually so high that the seismic response in the diagonal direction will remain before the yield deflection of beams. Especially in the design of super–high–rise buildings, the story drift responses against big earthquakes are usually limited within a certain value so that in super–high–rise buildings, the simultaneous yieldings of beams rarely occur.

In this discussion, the seismic design in all directions is necessary. However, it is not realistic. From this point of view, this paper discusses the method evaluating the design forces of columns which are connected with the beams in the two–way frame that do not yield in the diagonal directional loading. And also this paper proposes the method to evaluate the design forces of column in any design direction based on the force–deflection relationship in the frame direction that is able to be obtained precisely.

DIRECTION OF DESIGN EARTHQUAKE MOTION

As for an earthquake motion for design, two components of the earthquake should be considered. But it is not easy to take account the two directional effect of earthquake motion into the design due to many reasons as follows;

1) The relationship between the direction of design and input motions can not be determined reasonably.
2) There are some doubt of reliability and complexity of a 3–D analysis.
3) The evaluation method on the results provided by a 3–D analysis has not been established yet.

and

4) There are many combinations of a earthquake motion in each direction.

Analytical studies on two directional input earthquake motions have been conducted by many researchers. But these researches study the responses of some specific buildings against some specific earthquake motions. Any comprehensive results have not been able to be derived from these studies yet. This paper understands that each earthquake component is superposed into the one component earthquake motion, and the one component earthquake motion acts the building in any direction. This understanding is better than doing the multi–directional analysis using two components earthquake motions in order to consider the two dimensional effects of earthquake motions in the design sense. Designing against one component earthquake motions is equivalent to designing considering the response to the two directional earthquake motions with the same intensity and the same frequency characteristics in each direction. And it gives the most sever design condition, as far as the energy of one component earthquake motion is not less than that of two directional earthquake motions. Of course, two directional response analysis is necessary to the building with eccentricity and so on.

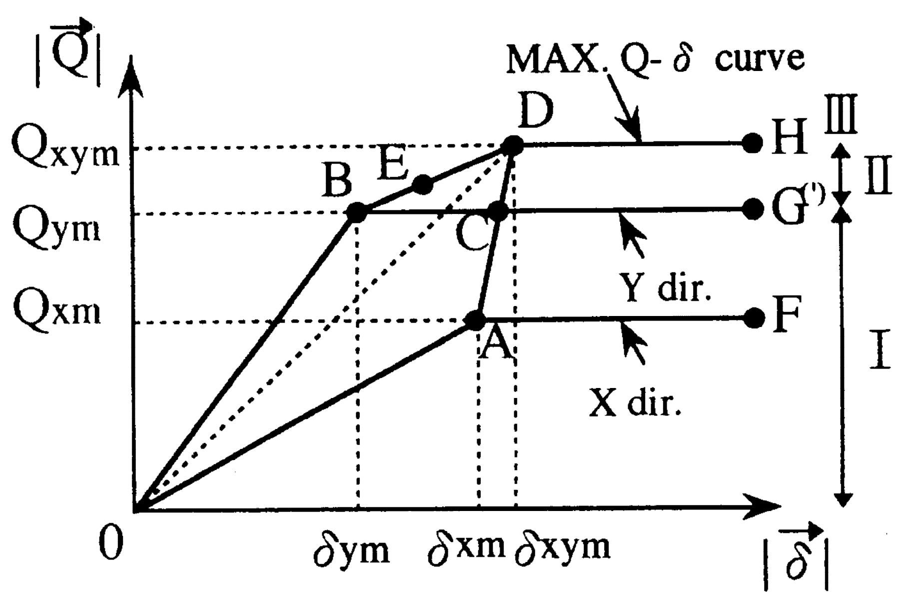
RELATIONSHIP BETWEEN YIELD SITUATION OF THE X- OR Y-FRAME AND ACTING FORCES OF COLUMNS

In a building with two–way frame system, seismic load resisting characteristics in any direction would be obtained by superposing those obtained by analysis in both frame directions. This assumption would be effective to the building whose seismic load resisting characteristics are dominated by yielding of beams. To simplify it, lateral force resisting characteristics of each frame are assumed to be a bi-linear type, focused on the shear force of vertical structural members.

Load-deflection characteristics in X- or Y-frame direction are shown in Fig.1. Line-OAF shows one in the X-frame direction, while line-OBG in the Y-frame direction. And also line-OADH(OBDH) represents the load-deflection relation tracing up to the yield deflection in the X(Y) direction and then in the Y(X) direction. Load-deflection characteristics in any directions exist in the zone area bounded by the line OAF and OBDH. Load-deflection relationship of OBDH gives the maximum forces in all load-deflection relationships at the same deflection.

Relationship between the yield situation of both X- and Y-frame and the deflection in any direction is illustrated in Fig.2. In the area bounded by X- and Y-axes and the line-BCG', the maximum forces of the column are less than those of the yield strength in the Y-direction(Zone-I). In the Zone-III where is the right-upper area from the point-D, corresponding to the line-DH in Fig.1, both X- and Y-frame are yielding. The maximum forces of column are given in this zone-III. In Zone-II that is the area bounded by Y-axis, the line-BCG' and Zone-III, force of columns is greater than the yield strength in the Y-frame (Qym). In the Zone-II, both X- and Y-frames remain in the elastic stage, or one of X- or Y-frame is beyond their yield deflection. There is no problem if the column design would be done using the forces defined in Zone-III as done in the seismic design code in N.Z.(1982). But for a building, such as a high-rise building whose earthquake response is expected to remain within a small inelastic range, the forces in Zone-III are too large for the column design, and the forces in Zone-I or Zone II would be reasonable.

We can get the design forces of columns at the deflection we want to design the building (defining as the design deflection) for any seismic direction utilizing Fig.1 and 2. Here the design deflection is defined as the deflection amplifying the expected earthquake response deflection by adequate safety factor. In allowable stress design concept, the check of stress is main work and subordinate the check of deflection is. However, the introduction of the concept of the design deflection is necessary for the design methods based on the ultimate strength concept and beam yielding type.



δ xm, Qxm : Yield deflection and strength in the X-dir.

δ ym, Qym : Yield deflection and strength in the Y-dir.

Fig. 1. Assumed load-deflection characteristics in X- or Y-frame direction.

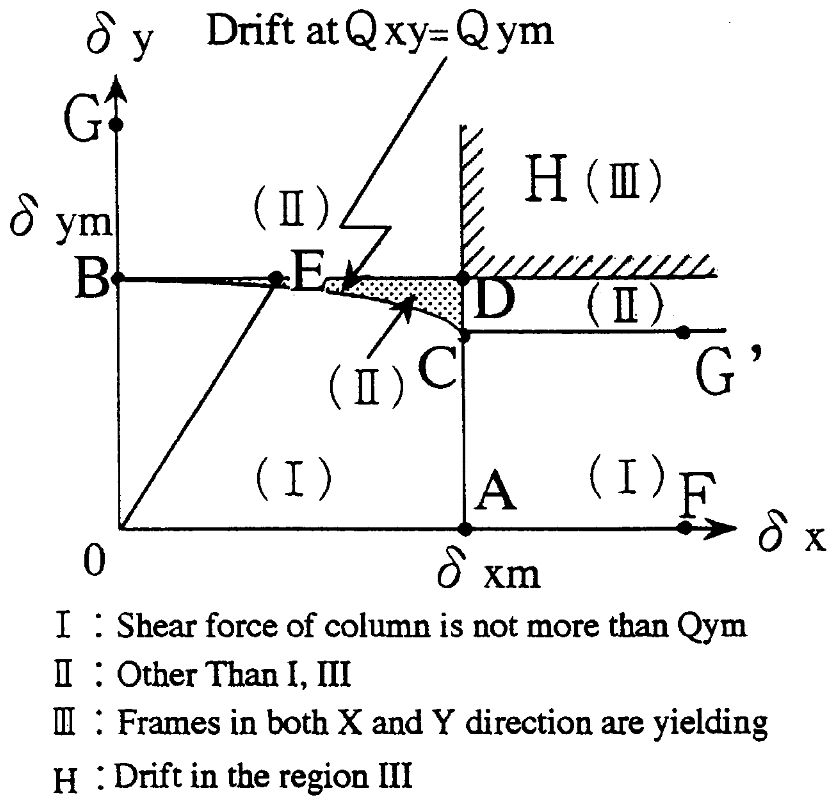


Fig. 2. Yielding situation of both X- and Y-frame and the deflection in any direction.

SCHEMATIC RESOLUTION TO EVALUATE THE MAXIMUM FORCES OF COLUMNS IN ANY DIRECTION

For the building whose seismic load resisting characteristics after yielding are dominated by those of beams, seismic design actions in any direction would be obtained by superposing those obtained by the analysis in both frame directions. Schematic resolution to evaluate the maximum forces of columns in any direction is proposed. The assumptions used in this proposal are :

1) each frame crosses orthogonally
2) inelastic interactive behavior of M–M–N in the vertical structural members(columns, walls) can be ignored
3) effect of torsional behavior of beams also can be ignored
4) the mechanical resisting system of transverse members such as transverse beams to walls is the same in all directions

Schematic Resolution For Moment And Shear Force

Maximum shear force (bending moment) will be obtained as follows (see Fig.3);

(1)In the 2nd. and the 4th. quadrants, the relationships of shear vs. drift for the Y–frame direction and for the X–frame direction are depicted, respectively.

(2)In the 1st. quadrant, the design drift is depicted. In the figure 3, the same design drift for any direction is assumed.

(3)Shear forces of the X–frame and the Y–frame corresponding to the design drift are obtained, and shear force for any direction at the design drift are superposed in the 3rd. quadrant.

(4)The length of vector from the origin of O to the contact point of C on the curve presenting shear force in any direction and the circle with center at the origin in the 3rd. quadrant represents the maximum shear force.

(5)The corresponding point on the curve of design drift in the 1st. quadrant to the point E shows the drift in each frame direction at the maximum shear force.

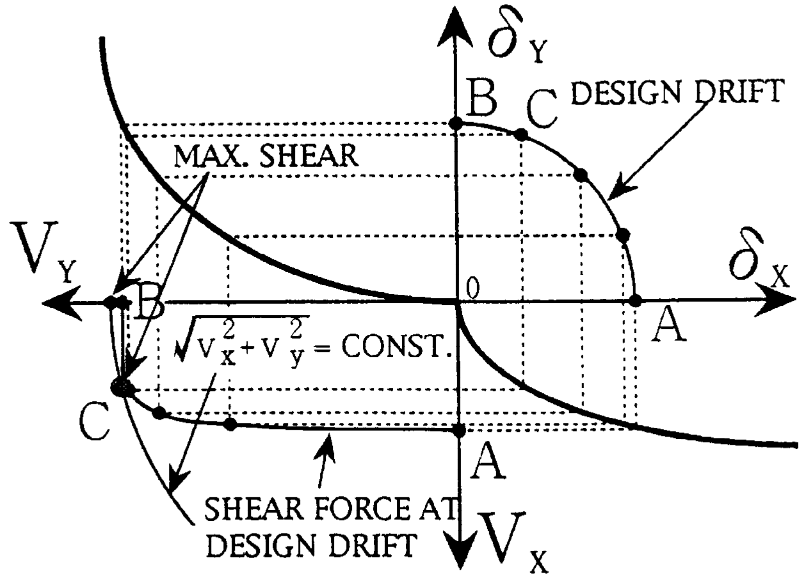


Fig. 3. Maximum column shear and bending moment by bi–directional loading

Schematic Resolution For Axial Force

Maximum additional axial force of corner columns will be obtained as follows (see Fig.4);
(1)In the 2nd. and the 4th. quadrants, the relationship of adding axial force vs. drift for the Y–frame direction and for the X--frame direction is depicted, respectively.
(2)The same as the case of maximum shear force
(3)The same as the case of maximum shear force
(4)The crossing point on the X–axis and the line with the angle of 45 degrees which has the contact with the point–C on the curve presenting adding axial force in any directions in the 3rd. quadrant represents the maximum adding axial force.
(5)The corresponding point on the curve of design drift in the 1st. quadrant to the point E shows the drift in each frame direction at the maximum additional axial force.

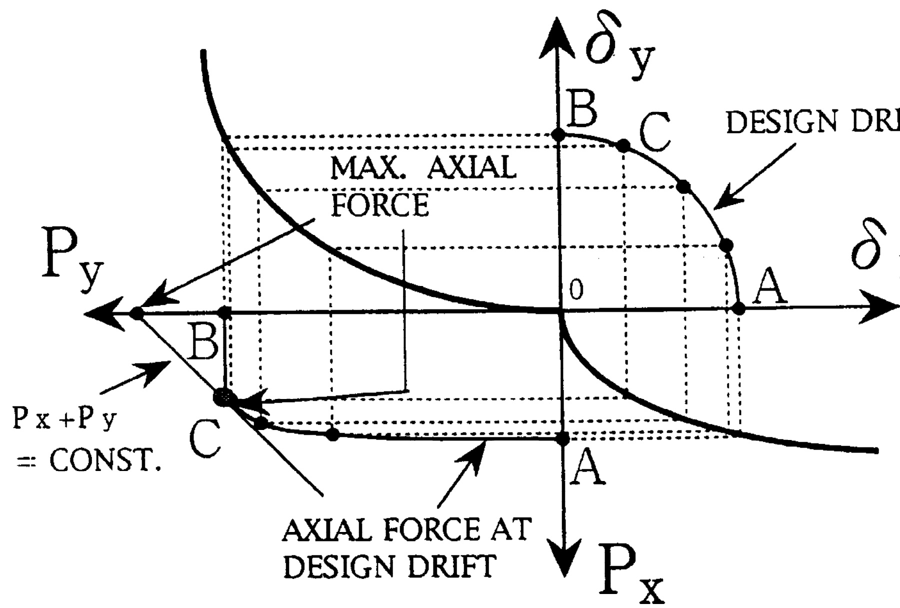


Fig. 4. Maximum additional axial force in corner column by bi–directional loading

CASE STUDIES AND RESULTS

By the proposed method evaluating the column shear and bending moment, the effect of several parameters are studied on the relationship between the differential ratio of Qmax to Qym or Q_{45}, i.e. (Qmax/max(Q_{45},Qym)−1). Qmax is the maximum shear force of vertical structural member obtained in specified direction and Q_{45} is the shear force obtained by an analysis in 45 degrees direction. Because the discussion in the 45 degrees direction is often conducted at a practical design, the ratio of (Qmax/max(Q_{45},Qym)−1) is important. The parameters considered in this study are the yield strength (Qxm, Qym) and yield deflection(Dxm, Dym) in each frame direction. And the design deflection is assumed to be the same in all directions.

Figure 5 shows the relationship between (Qmax/max(Q_{45},Qym)−1) and the design deflection. In this case, yield strength of both frame directions (Qxm and Qym) are assumed to be the same, and yield deflection of X-direction, Dxm, is β times of that of Y-direction, Dym. Design deflection is represented by rxDym. The dotted line−1 represents (Qmax/Q_{45}−1), and the thin line−2 represents (Qmax/Qym−1). The smaller value is the ratio of (Qmax/max(Q_{45},Qym)−1). The smaller β is, and the larger both β and r are, the more important the analysis in 45 degrees is. The thick line−3 gives the upper boundary limit of (Qmax/max(Q_{45},Qym)−1). This line−3 also indicates the importance of the analysis in 45 degrees direction. No matter what value of β and r, (Qmax/max(Q_{45},Qym)−1) is not more than 22.5%, and when β is smaller this value is less than 10%.

Next results are derived:

1)In the case that the load vs. drift relation in the X− and Y−frame direction is not different so much, the differences between the column forces in the direction of 45 degrees and the maximum those are less than 10%, and

2)in the case that the load vs. drift relation in the X− and Y−frame direction are different so much, the maximum forces of column are close to those in the frame with high yield strength.

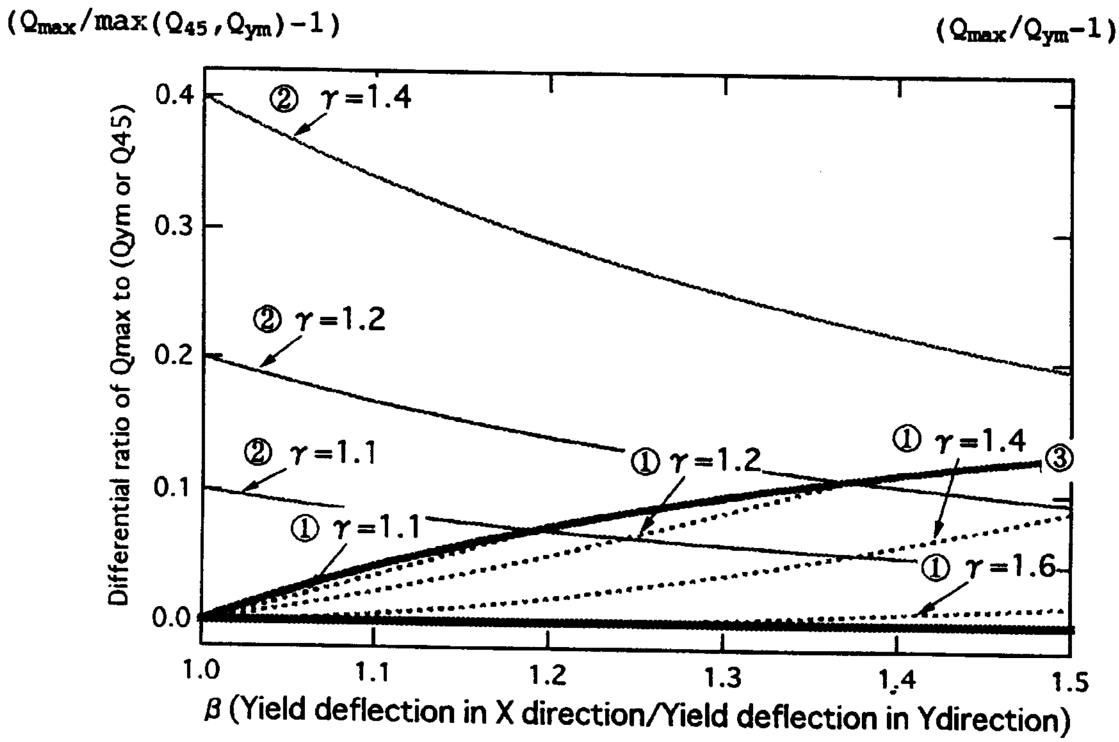


Fig. 5. (Qmax/max(Q_{45},Qym)−1) at the same yielding strength in both X and Y frame directions

CONCLUSION

The necessity to examine the column forces in the off–frame direction as well as in the two frame directions is presented. And schematic resolution to evaluate the maximum forces of columns in any direction is proposed by the assumption that each frame crosses orthogonally and is dependent. In case that restoring force characteristics in each frame direction is bi–linear type, the differences between the maximum forces and those in 45 degrees direction for vertical structural members are discussed.

REFERENCES

Ben Kato (1983). Seismic Design for Steel Structure. Maruzen, Tokyo

STANDARD ASSOCIATION OF NEW ZEALAND (1982). NEW ZEALAND STANDARD Code of practice for THE DESIGN OF CONCRETE STRUCTURES. NZS 3101