



DAMAGE TO 11-STORY SRC CONDOMINIUM BY HANSHIN EARTHQUAKE IN 1995

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ABSTRACT

An 11-story SRC condominium in Hyogo prefecture was damaged by the earthquake (M=7.2) in January 17, 1995. The investigation of damage to this building was conducted in order to judge the structural safety and find the repair procedure.

The main damage of this building is the tensile fracture of reinforcing bars of the first story column. The tensile fracture of reinforcing bars can not explain by some conventional analyses. The tensile fracture of reinforcing bars may occur because of strain concentration. If a continuous structural wall assume a cantilever, this phenomenon can not explain.

A deforming model assumed in this paper derives strain concentration to reinforcing bars at the bottom of the first story column which is placed at the edge of continuous structural walls. The tensile fracture of reinforcing bars occur when the drift angle reach to 1/100-1/50 radian.

KEYWORDS

Seismic evaluation; SRC structure; tensile fracture of reinforcing bar; theory of plasticity

INTRODUCTION

The seismic evaluation is very important for judging the safety of a damaged building by big earthquake such as HANSHIN earthquake. The safety of a damaged building is judged by various points, width of cracks, residual drift angle and so on. A damage that can not explain by some analyses is embarrassed the inspectors.

The tensile fracture of reinforcing bars can not explain by some conventional analyses. The tensile fracture of reinforcing bars may occur because of strain concentration. If a continuous structural wall assume a cantilever, this phenomenon can not explain.

This paper explains the reason of the tensile fracture taking account of bi-axial horizontal deformation effect. A deforming model assumed in this paper derives strain concentration to reinforcing bars at the bottom of the first story column which is placed at the edge of continuous structural walls.

OUTLINE OF BUILDING

The damaged building is a 11-story SRC building that was completed in 1981 (see Photo. 1). Fig. 1 shows a typical floor plan. The short side (N-S direction) is based on a continuous structural wall, and the length is about 10 meters. The long side (E-W direction) is based on ductile moment-resisting frames, and the length is about 80 meters. Fig. 2 shows a section of this building. The height of this building is about 30 meters. The lower floor (G-4FL) is SRC structure, and the higher floor (5-11FL) is RC structure.



Photo. 1 Exterior view

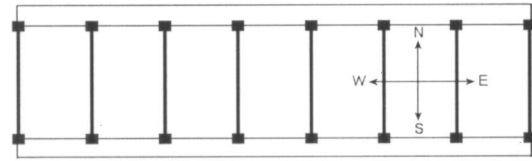


Fig. 1 Typical floor plan

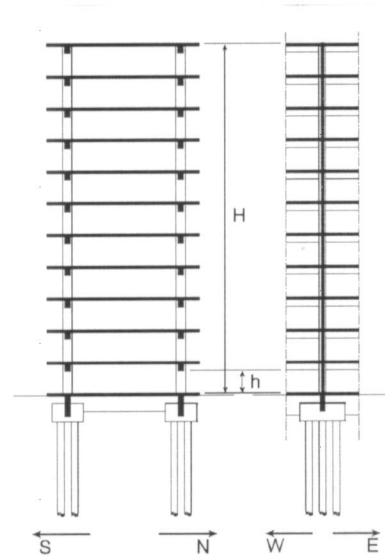


Fig. 2 Section

EXTENT OF DAMAGE

The investigation had been performed twice. The first investigation was performed for the purpose of grasping the outline of the damage and of taking the emergency measurement. The second one was done to inspect the stricken degree of this building.

After the investigation, the following damage was seen.

- 1) The tensile fracture of reinforcing bar of the bottom of the first story column was seen (see Photo. 2 & Fig. 3).
- 2) The tensile fracture of anchor-bolts of the bottom of the first story column was seen.
- 3) The tensile fracture of steel of the top of the second story column was seen.
- 4) The destruction of concrete of lower floor was seen.



Photo. 2 The first story column destruction

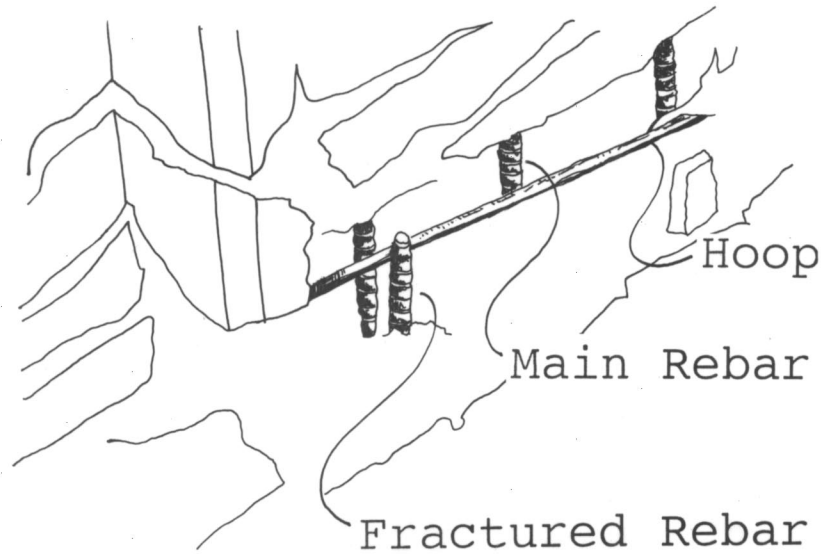


Fig. 3 Sketch of Photo. 2

ANALYSIS

The tensile fracture of reinforcing bars of the bottom of the first story column can not explain the simple theory. Therefore the authors examine the reason of this tensile fracture of reinforcing bars.

Modeling of Building

The building is assumed as shown in Fig. 4. The height of the building was H , the height from the floor to the bottom of the girder was h , and the weight of each floor was assumed equal.

Lateral Load Distribution

The lateral load distribution is assumed A_i distribution (defined in Notification No. 1793 of Ministry of Construction, issued in 1980).

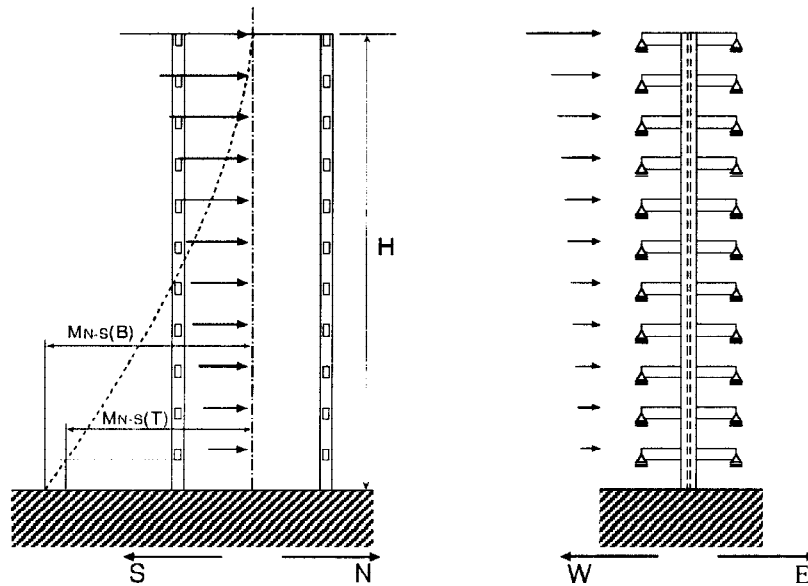


Fig. 4 Modeling of building

Modeling of Column

The column is assumed as shown in Fig. 5. The sectional area is A_s , the distance from the reinforcing bar of compression to the reinforcing bar of tension is D . The west side reinforcing bar is RB_w , and the east side reinforcing bar is RB_E .

Modeling of Deformation

In this paper three states are discussed as shown in Fig. 6, i.e. :

- State(i) : N-S direction deformation only.
- State(i+1) : after state(i), E-W direction deformation is occurred.
- State(i+2) : after state(i+1), opposite E-W direction is occurred.

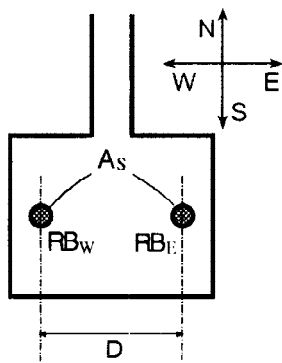


Fig. 5 Modeling of column

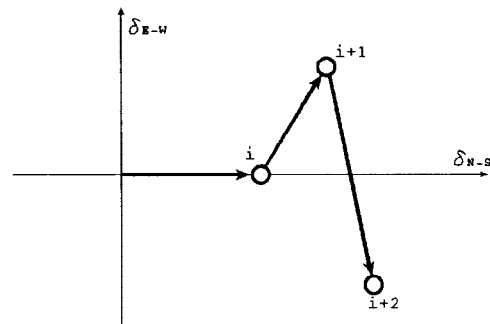


Fig. 6 Modeling of deformation

Assumption of Stress and Strain of Reinforcing Bars (1)

The stress and strain of reinforcing bars is assumed as shown in Fig. 7. The bottom is just before strain hardening at state(i). At state(i+1) RB_w starts strain hardening and RB_E is unloaded. The top is elastic at state(i). At state(i+1) RB_E is yield and RB_w is unloaded.

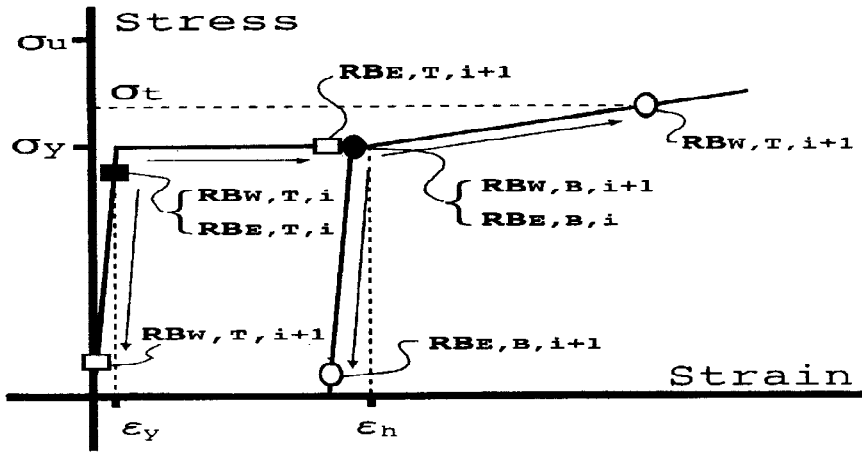


Fig. 7 σ - ϵ relationship

Bending moment-curvature-axial force-axial deformation relationship of column section

There is an analogy between bending moment-curvature-axial force-axial deformation relationship and the theory of plasticity as shown in Fig. 8.

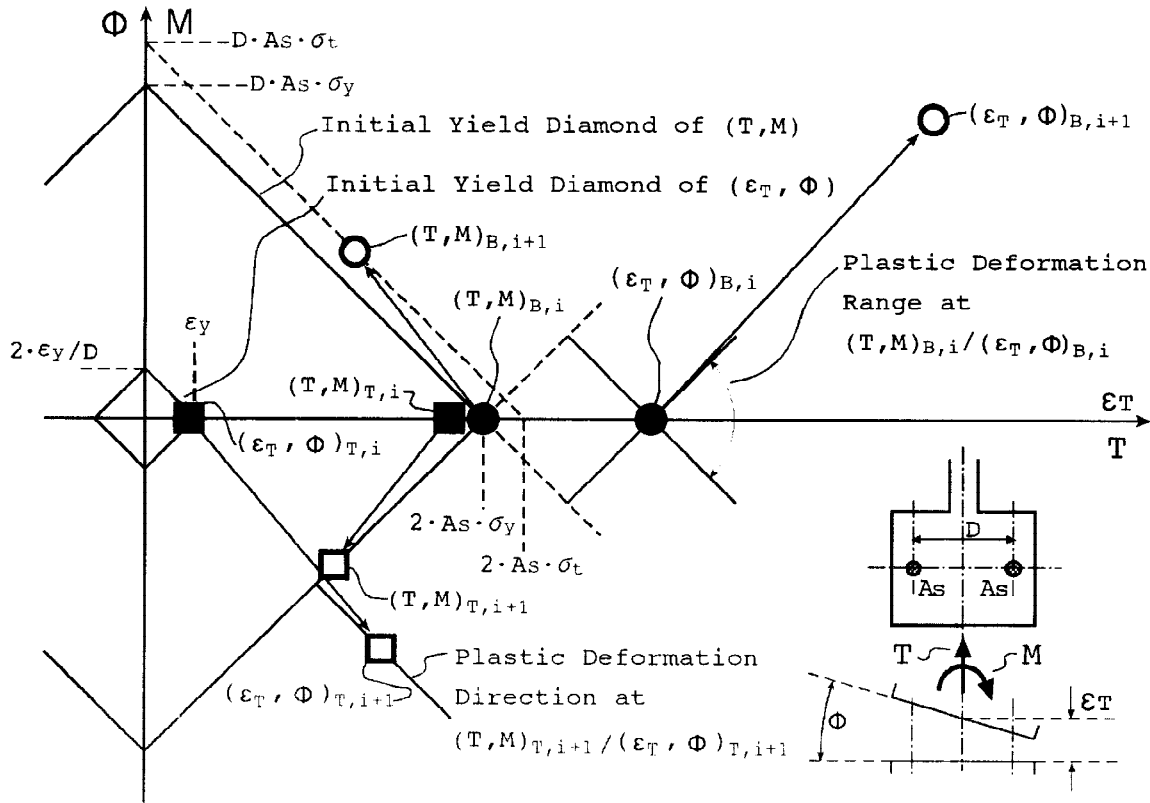


Fig. 8 Analogy of M - ϕ - T - ϵ_T relationship to the theory of plasticity

Stress Distribution of Reinforcing Bars (1)

The stress distribution of reinforcing bars are assumed Fig. 9(a) from Figs. 7 & 8. The strain distribution of reinforcing bars are shown in Fig. 9(b). And the real distribution is supposed as shown in Fig. 9(c).

The total elongation of reinforcing bars of west side is equal to the total elongation of reinforcing bars of east side without the bending deformation of girders that connects with top and bottom of the column.

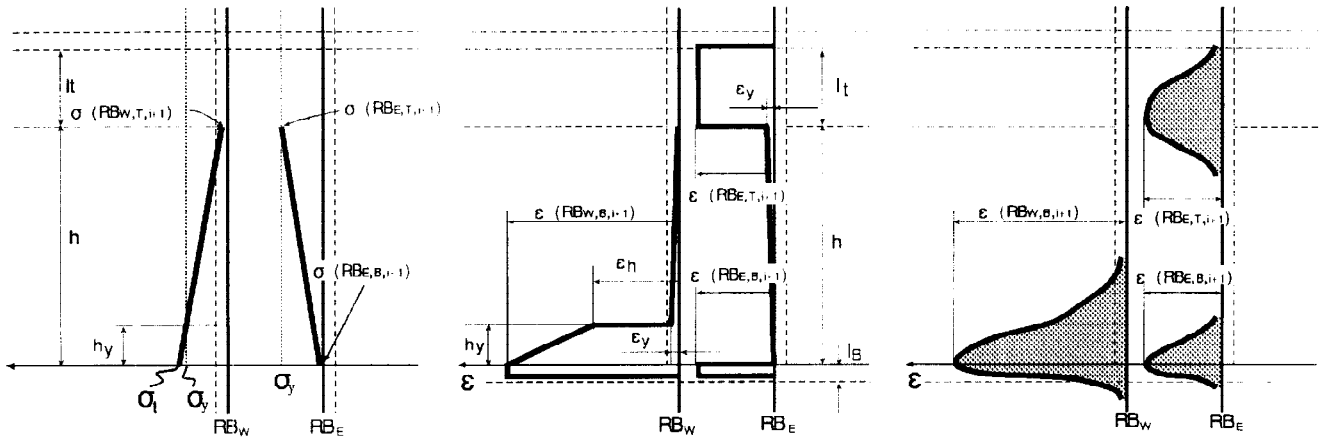


Fig. 9 Stress and Strain distribution of reinforcing bar

Local Bending Moment

If reinforcing bars are yield by tensile force, cracks may be occurred as shown in Fig. 10. In this condition the local bending moment and shearing force of reinforcing bars are occurred as shown in Fig. 10.

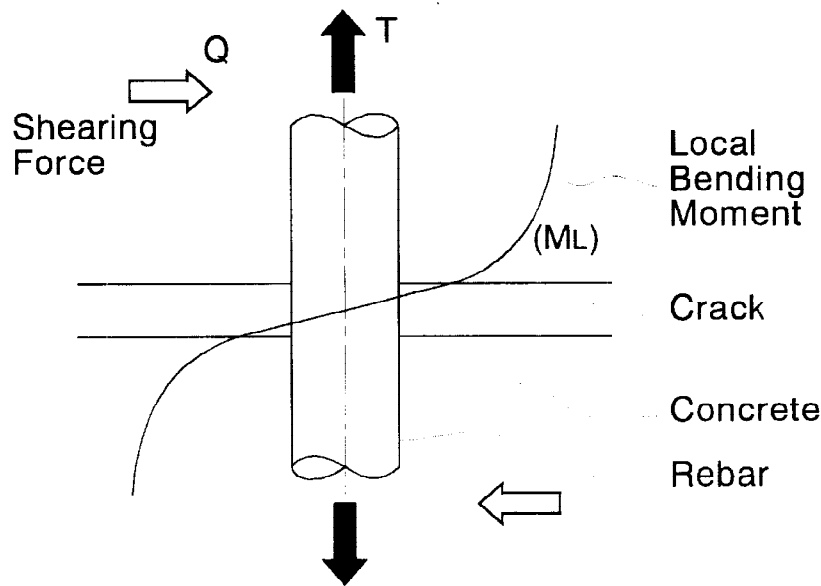


Fig. 10 Local bending moment

T-Q & M-T Relationship

The local bending moment of reinforcing bars is assumed as shown in Fig. 10, T-Q relationship may be expressed as shown in Fig. 11. And also M-T relationship may be expressed as shown in Fig. 12.

Considering these assumption, α_y of reinforcing bar yielded by tensile force decrease.

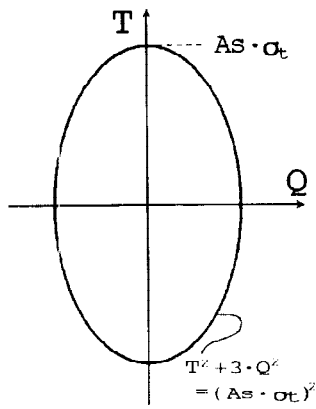


Fig. 11 T-Q relationship

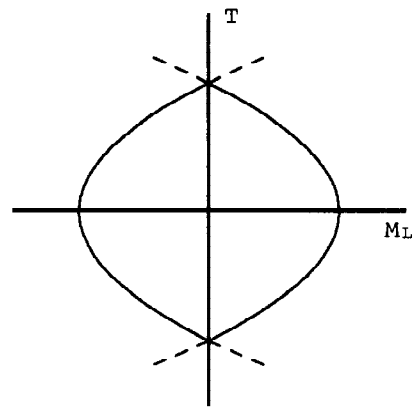


Fig. 12 M-T relationship

Assumption of Stress and Strain of Reinforcing Bars (2)

At state(i+2), the stress and strain of reinforcing bars is assumed as shown in Fig. 13. At the bottom of the column, RB_E starts strain hardening and RB_W is unloaded. At the top RB_W is yield and RB_E is unloaded.

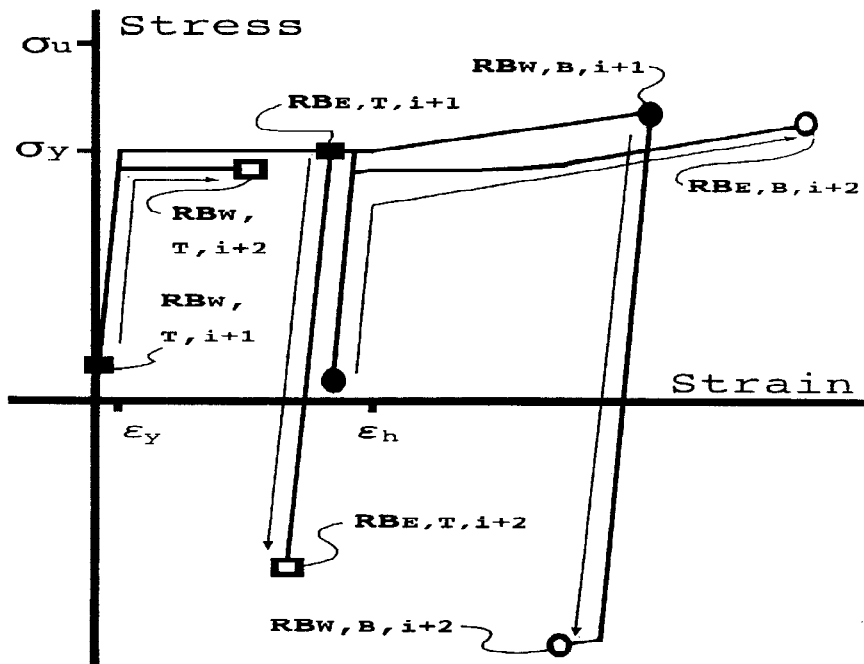


Fig. 13 σ - ϵ relationship

Strain Distribution of Reinforcing Bars (2)

A continuous structural wall to develop plastic deformation by flexural yielding under the action of bending may be deformed as shown in Fig. 14(right). The strain distribution of reinforcing bars are supposed Fig. 14(left).

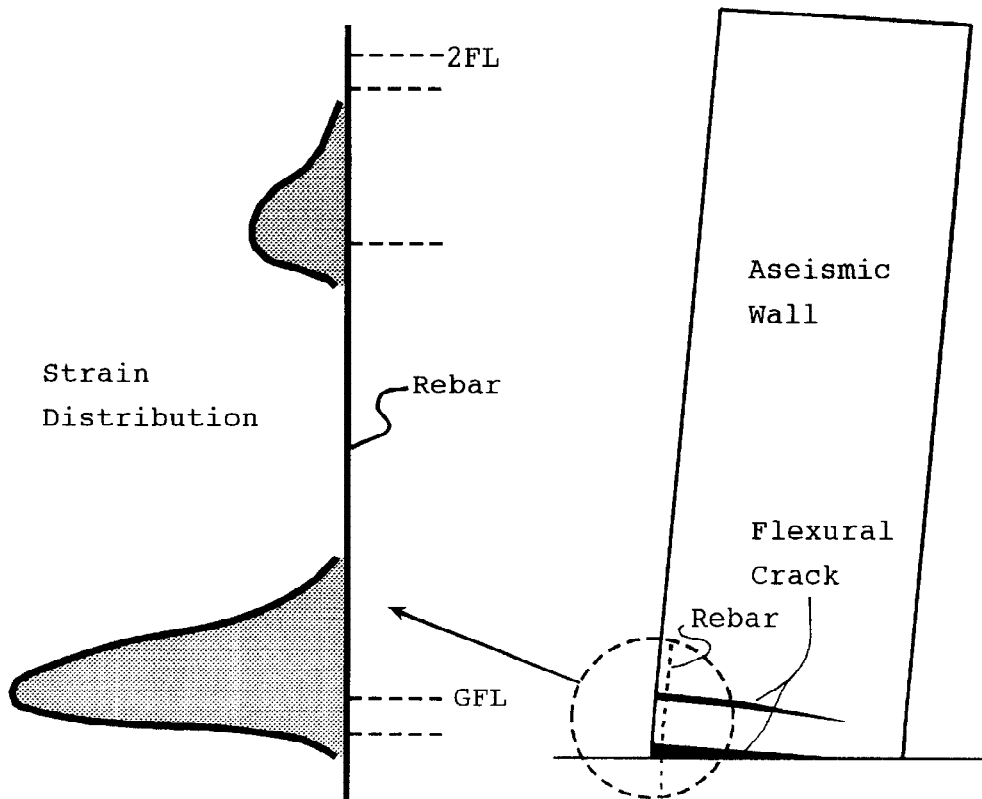


Fig. 14 Strain distribution of reinforcing bar

CONCLUSION

This paper explains the reason of the tensile fracture taking account of bi-axial horizontal deformation effect. This deforming model assumed in this paper derives strain concentration to reinforcing bars at the bottom of the first story column which is placed at the edge of continuous structural walls. Assuming to the strain concentrate region is $30d$ (d : diameter of reinforcing bar), main reinforcing bar is D25 ($d=25\text{mm}$) and the elongation of reinforcing bar is 20%, the tensile fracture of reinforcing bar occur when the drift angle reach to $1/100$ - $1/50$ radian.