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Hysteresis Model for the Shear Behavior of R/C Multistory Frame Buildings with Diaphragms Under Seismic Actions (Part 2)
——Rules of Formation——

耐震壁を有する鉄筋コンクリート造多層建物のためのせん断履歴モデル
——その2 履歴ルール——

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1. Introduction

This paper is continuation of the first part where principle of hysteresis model formation was stated [1]. In order to develop a nonlinear response analyses program for multistory buildings using proposed model it is necessary to define the hysteresis rules for R/C diaphragms (shear walls) behavior.

Before to expound the hysteresis rules let's assume following definitions and notations:

loading—an increase of the force without change in sign;

unloading—a decrease of the force without change in sign;

load reversal—change in sign of the force with respect to the last load step;

SC, SY, SU, SO—tangent stiffness in elastic, cracking, yielding and ultimate stages, respectively;

DC, FC—displacement and force in cracking point, respectively;

DY, FY—displacement and force in yielding point, respectively;

DU, FU—displacement and force in ultimate point, respectively;

DO—displacement at collapse;

DS, FS—previous value of displacement and force, respectively;

DM^{+-}, FM^{+-}—previous maximum value of displacement and force, respectively;

DR^{+-}—residual deformation;

SS, DD, FF—current stiffness, displacement and force, respectively.

2. Rules of Hysteresis Model Formation

The assumed notations are indicated in the Fig. 1 where also numerals in circles denote the numbers of following rules.

Rule 1: elastic stage (Fig. 1a, b, c)

1.1 loading

1.1.1 FF≦FC: SS=SC, FF=SC×DD, go to rule 1.

1.1.2 FF>FC: SS=SY, go to rule 2.

1.2 unloading and load reversal: SS=SC, go to rule 1.

Rule 2: loading on the primary curve from cracking point up to yielding point (Fig. 1a, b, c, d)

2.1 loading

2.1.1 FC<FF≦FY: SS=SY, FF=FS+SY×(DD−DS), go to rule 2.

2.1.2 FF>FY: SS=SU, go to rule 3.

2.2 unloading from point (DM^{+-}, FM^{+-}) and load reversal

2.2.1 FM>FF≧FC: SS=SC, go to rule 6.

Rule 3: loading on the primary curve from yielding point up to ultimate point (Fig. 1a, b, c, d)

3.1 loading

3.1.1 FY<FF≦FU: SS=SU, FF=FS+SU×(DD−DS), go to rule 3.

3.1.2 FF<FU and DD>DU: SS=SO, go to rule 4.

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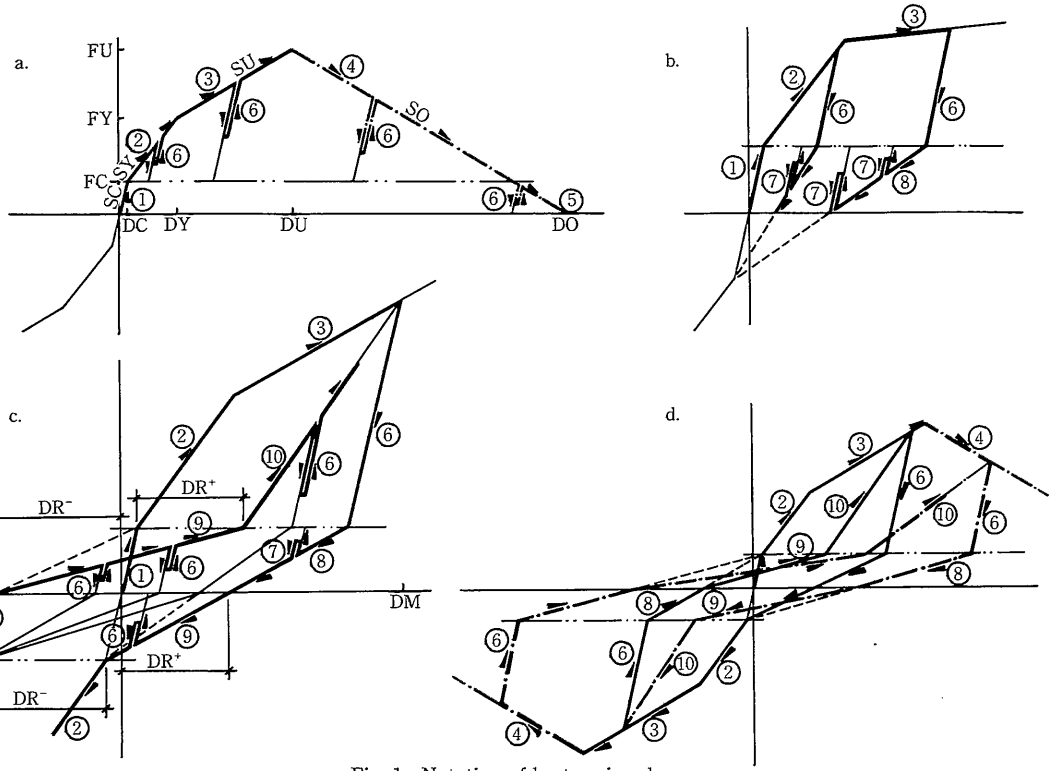

Fig. 1　Notation of hysteresis rules

3.2　unloading from point (DM^{+-}, FM^{+-}) and load reversal

3.2.1　FM>FF≧FC: SS=SC, go to rule 6.

Rule 4: loading on the primary curve from ultimate point up to collapse (Fig. 1a, d)

4.1　loading

4.1.1　FF<FU and DD>DU: SS=SO, FF=FS+SO×(DD−DS), go to rule 4.

4.2　unloading from point (DM^{+-}, FM^{+-}) and load reversal

4.2.1　FM>FF>FC: SS=SC, go to rule 6.

4.2.2　FC≧FF>0: SS=SC, go to rule 6.

Rule 5: Collapse (Fig. 1a)　FF=0.

Rule 6: unloading from points located on loading lines and load reversal (Fig. 1a, b, c, d)

6.1　after rules 2, 3, 4, 10

6.1.1　FU>FF≧FC: SS=SC, FF=FS+SC×(DD−DS), go to rule 6.

6.2　after rule 9

6.2.1　FC≧FF>0: SS=SC, go to rule 6.

Rule 7: loading from points located on unloading lines and load reversal (Fig. 1b, c)

7.1　after rule 8 FC>FF≧0: SS=SC, FF=FS+SC×(DD−DS), go to rule 7.

Rule 8: unloading from level FC up to 0 after rule 6 (Fig. 1b, c, d)

8.1　unloading

8.1.1　FC>FF>0: SS=(FC+|FS|)/(DC+|DS|), FF=FS+SS×(DD−DS), go to rule 8.

8.2　loading and load reversal

8.2.1　FC>FF≧0: SS=SC, go to rule 7.

Rule 9: loading from level 0 up to FC after rules 6 and 8 (Fig. 1c, d)

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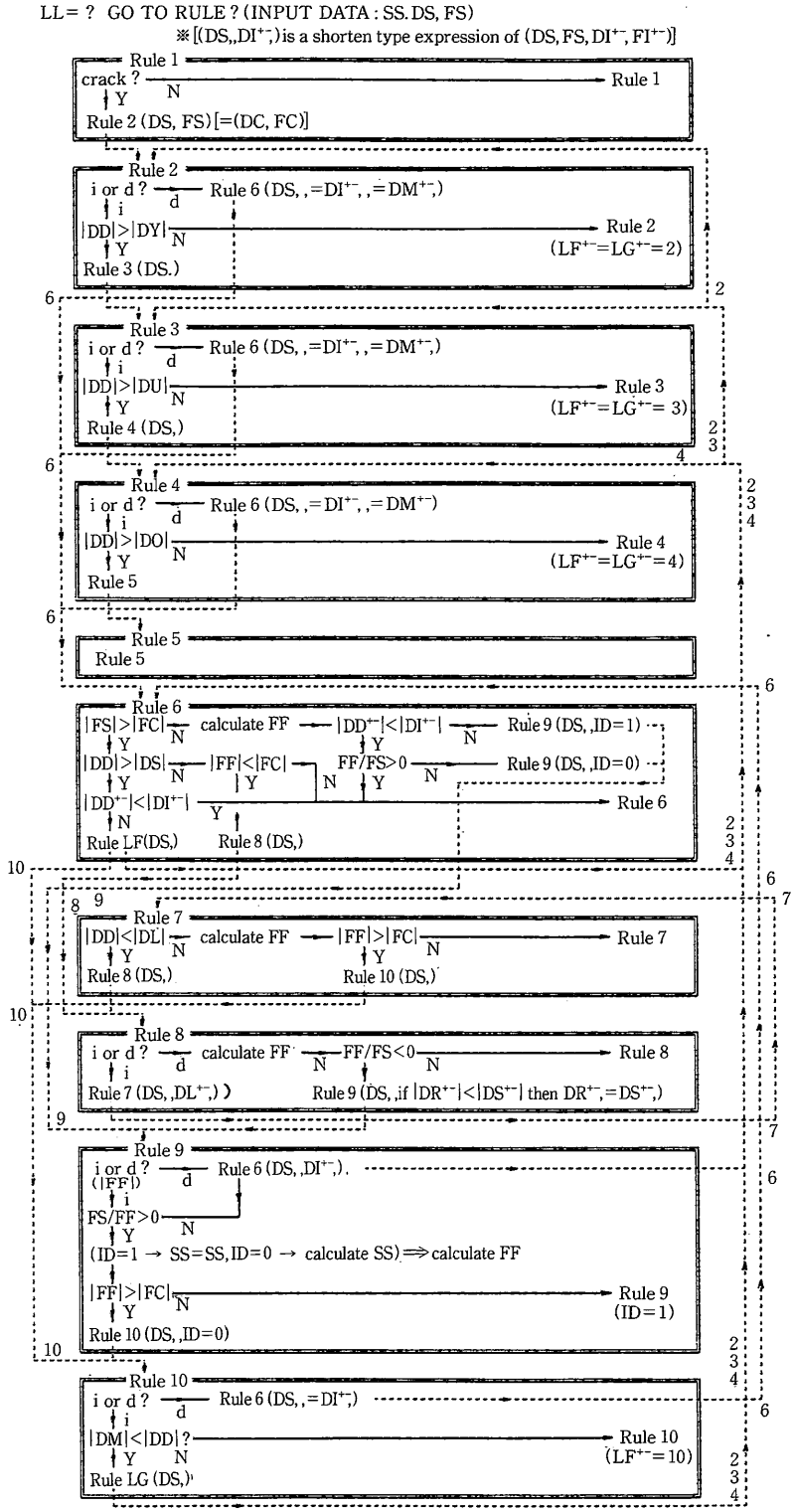

Fig. 2 Flow chart

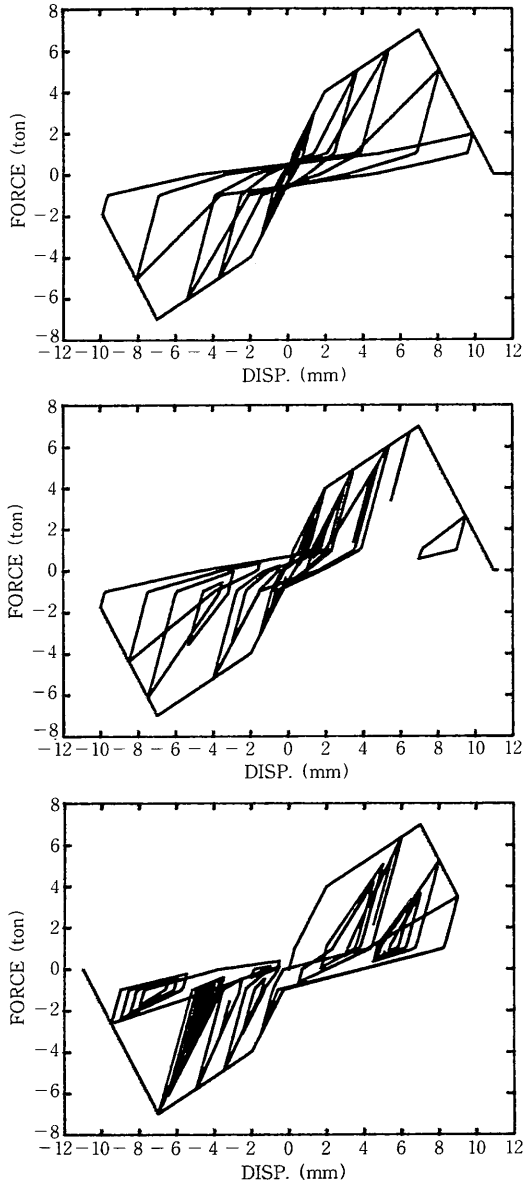

Fig. 3 Hysteresis loops for different loading histories

9.1 loading

9.1.1 FC>FF>0: SS=FC/(|DR⁻|+DC+DS), if FS<0,
SS=FC/(DR⁺+DC−DS), if FS>0,
FF=FS+SS×(DD−DS), go to rule 9.

9.2 unloading

9.2.1 FC≧FF>0: SS=SC, go to rule 6.

Rule 10: loading from level FC up to FM after rules 7 and 9 (Fig. 1c, d)

10.1 loading

10.1.1 FM>FF>FC: SS=(FM⁺−FC)/(DM⁺−DS),
if FS≧0,
SS=(|FM⁻|−FC)/(|DM⁻|−DC),
if FS<0,
FF=FS+SS×(DD−DS), go to rule 10

10.2 unloading

10.2.1 FM≧FF≧FC: SS=SC, go to rule 6.

On the basis of cited above rules the program was developed using the flow chart in Fig. 2. Here "i" or "d" means the question about increasing or decreasing of displacement with respect to the previous loading stage. By this program proposed hysteresis model can be used in nonlinear earthquake response analyses both for single degree of freedom and multi degree of freedom R/C frame systems with predominance of shear deformations. As an example, in Fig. 3 hysteresis loolps for shear wall are shown for three different arbitrarily given loading histories.

3. Concluding remarks

The rules of hysteresis model formation proposed to describe the shear behavior of R/C structures are stated. On the basis of that rules the program was developed for using new hysteresis model in nonlinear earthquake response analyses of multistory R/C buildings.

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References

1) Melkumian, M.G., Hysteresis Model for the Shear Behavior of R/C Multistory Frame Building with Diaphragms Under Seismic Actions (Part 1)—Principle of Formation, "SEISAN-KENKYU" Monthly Journal of Institute of Industrial Science, University of Tokyo, Vol. 42 No. 12 (1990), pp. 34-37.