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HYSTERETIC SHEAR MODEL FOR REINFORCED CONCRETE CONNECTIONS IN PREFABRICATED SHEAR WALLS

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ABSTRACT:

The shear force-shear displacement hysteretical models can predict strength, stiffness and ductility characteristics under cyclic loading for the connections in reinforced concrete prefabricated shear walls. The proposed model consist of primary shear force-shear displacement relationship under monotone loading and reloading. The primary curve used for the development of the model is considered as an envelope for the hysteretical relationship. It is a polygon with well-defined points of cracking and ultimate load and the corresponding shear displacement. Large number of test data in scale 1:2 were used to obtain the rules for unloading and reloading branches. The rules obtained through statistical analysis predict experimentally obtained stiffness degradation and pinching of the hysteresis loops. The branches of the hysteretic model are expressed in terms of selected parameters as displacement ductility ratio, number of cycles and level of axial load. The proposed model shows a good agreement with the experimental data.

KEYWORDS

Reinforced concrete, connection, cyclic loading, hysteretical model, stiffness, ductility, strength.

INTRODUCTION

The investigation of reinforced concrete structures supposes available analytical models that can forecast the mechanical characteristic of the elements subjected to cyclic loading. For reinforced concrete elements subjected to bending or bending with shear, the mathematical models permit a reasonably accurate prediction of hysteretic response. The behavior of prefabricated reinforced concrete structures is quite different in comparison with cast in sito. They consist of plain elements, assembled together by dry or wet connections. In prefabricated shear wall structures the connections are the weak links and they are determined as a critical regions in these types of buildings. The plane in witch the connections are placed is working like predetermined crack and the deformations and failures are localized in them.

The connections are loaded to shear and axial forces. The response of the connections depends on the geometry, material properties and the level of shear and axial loads. The main mechanisms defining the

Test of specimens in scale 1:2 was carried out (Nikolov et al. 1990). The experimentally received relationships for shear force-shear displacement were used as a base for further investigation. Through a statistical analysis of experimental data were defined the rules describing the branches of the hysteretical model. Some of the main parameters as initial stiffness, shear force at first sliding in contact plane and the corresponding displacement, whose influence on the behavior is significant, were defined by analytical investigation.

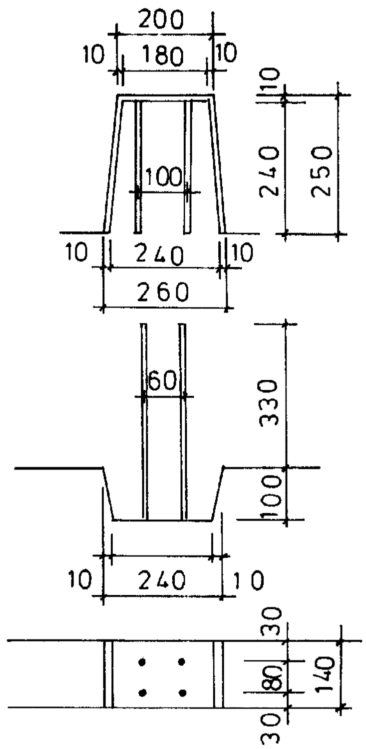

Fig.1. Type and geometry the considered connections

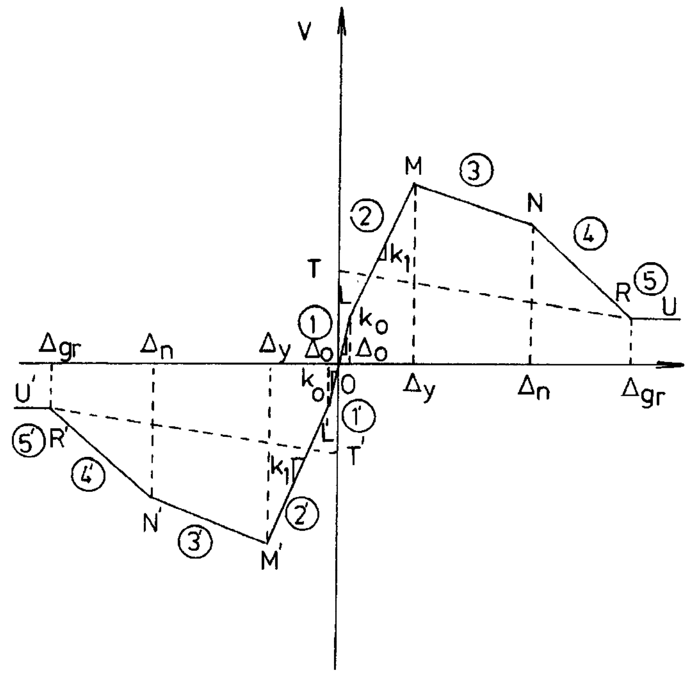

Fig.2 Primary curve

Up to now some hysteretic models for connections in prefabricated shear walls are proposed (Bozinowski, et al., 1990),(Schricker V.et al. 1980).Each of the proposed model is applied to exact type of connection, with determinate geometry and mechanical properties. A mathematical model has been developed to define the shear force- shear displacement hysteretic relationship for connections in prefabricated shear walls. The type of connections and the geometrical characteristics are given on fig.(1).

DESCRIPTION OF THE MODEL

The hysteretic model consists of primary curve for shear force-shear displacement relationship and set of rules for unloading and reloading branches.

Primary curve

The primary curve is an envelope for the hysteretic relationship and could be considered as one received under monotone loading. It is assumed that the primary curve is symmetrical polygonal curve of fife parts OLMNRU (O'L'M'N'R'U') and is used to define the boundary for shear strength for modeling (fig 2.).

Full-scale tests under monotone loading and analytical investigation (dissertation) were used to define the points of first sliding in contact plane (L), ultimate loads (M), points on descending branch (N,R) and the displacement (Δy) are established through a statistical analysis of experimental data received from a full-scale test. On fig.(3) the considered part of shear wall in the vicinity of the connection and the assumed

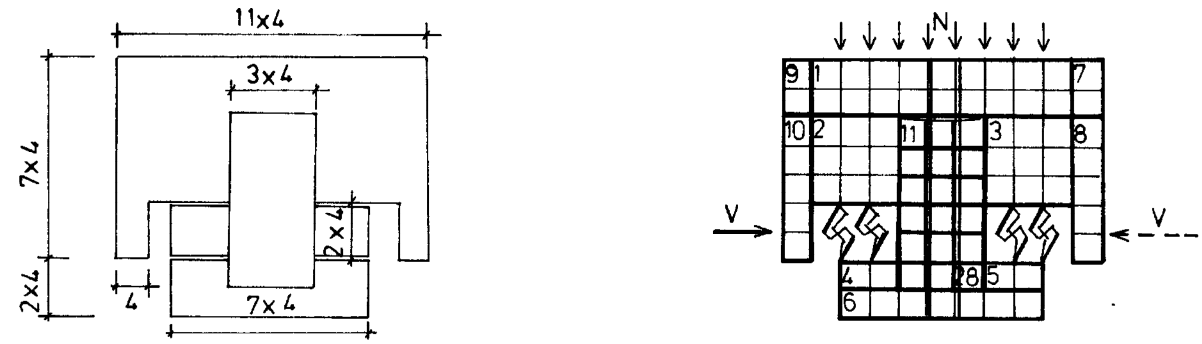

Fig.3. Mathematical model and type of loading

mathematical model are shown. The vertical axial load (N) (compression, zero or tension) is kept constant during the investigation. The part of the floor slab and the contact plane in which the sliding has occurred is modeled by nonlinear springs.

The horizontal action is assumed to be only in one point. This permits the descending branch of the primary curve to be received if the analytical investigation is carried out by displacement control. For this purpose the horizontal displacement is increased step-by-step from zero to its ultimate value.

The behavior of the connection depends on several parameters as level of axial load, steel ratio, roughness of the contact plane, value of friction coefficient (μ) and its diminishing with the increase of the displacement. The shear force - shear displacement relationship from the analytical investigation is given on fig.(4). The variation of the initial stiffness depends on the level of vertical axial load and the results are given on fig.(5). The stiffness of uncracked specimen k_{so} and the maximum shear force V_{max} reflect the effects of geometry, material properties, reinforcement, friction coefficient and the interaction between shear and axial loads. Each one of these two parameters is received in two different manners. Once by statistical analysis of experimental data and second time by analytical investigation.

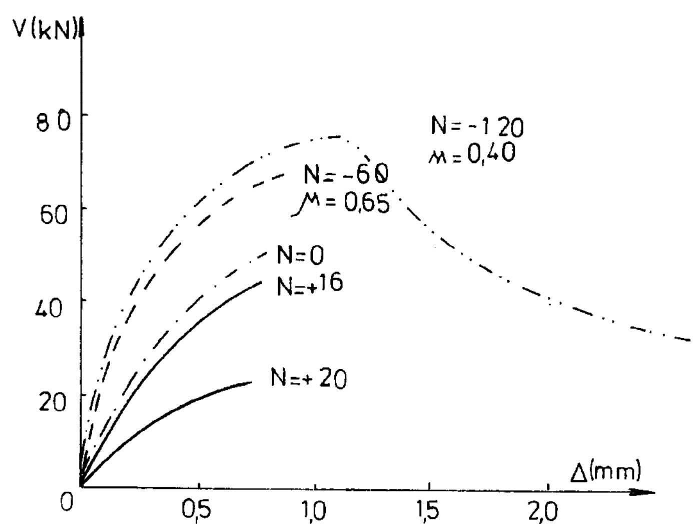

Fig.4. Shear force-shear displacement relationship from analytical investigation

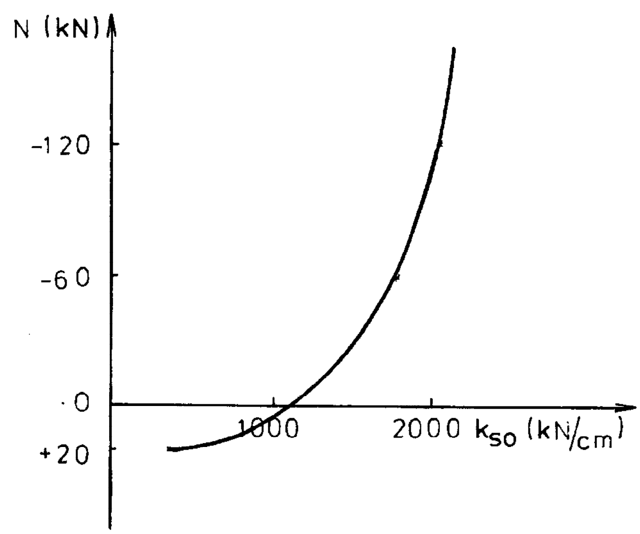

Fig.5. Axial load-initial stiffness relationship for virgin specement

Response under load reversals

To receive the unloading and reloading branches of the hysteretic model, experimental data from the cyclic test in scale 1:2 (Moscow) was used. The branches of the hysteretical model are expressed in terms of selected parameters as displacement, ductility ratio, number of cycles and level of axial load.

Unloading: Two parameters of the primary curve, the initial stiffness of virgin specimen k_{so} and the slope of line connecting the sliding point L with a point of maximum shear force M labeled as k_1 are used as a base to determine the unloading branches of cyclic loading. The point L is determined as a point at witch the shear force in inelastic springs is bigger than the retaining force received by multiplying the normal force in spring by the coefficient of friction.

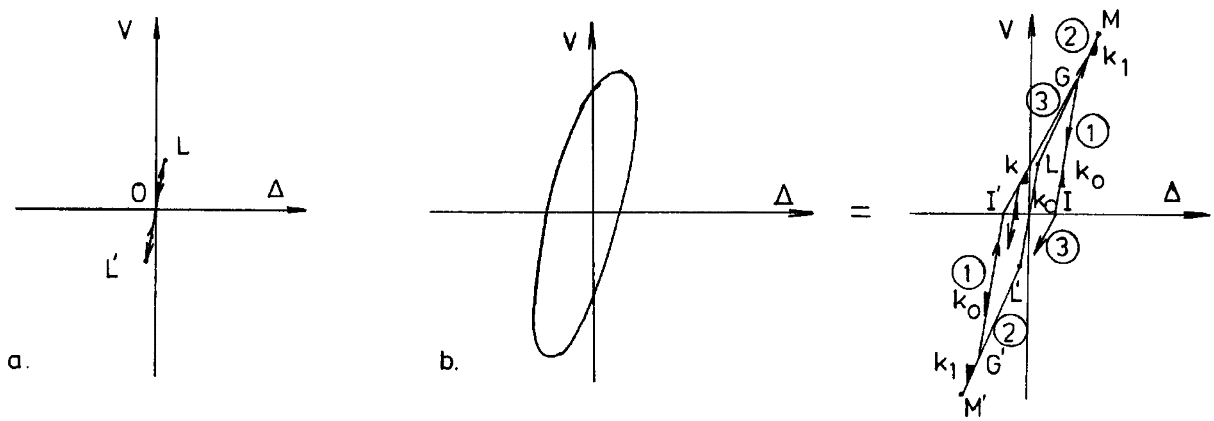

Fig.6 Segments of Proposed Hysteretic Model Befor Maximum Shear Force

The displacement at point L is about 0,07-0,14 mm. (average value 0,1 mm). Up to the point L no hysteretic behavior is observed (fig.6a). Unloading follows the primary curve if the shear force at the beginning of unloading is less than the load of first sliding (point L). The level of deformation by unloading has a significant influence on the slope of unloading branch.

The main principles in application of the model are:
- By initial loading or loading in one of the next cycles (part LM) and when the primary curve is reached, the movement continue along the primary curve up to the point M.
- By loading in part MN or NR and the line TR is crossed the stiffness decrease with the number of cycles.
- The stiffness changes its value:
- as the shear changes its direction
- as the line TR (T'R') is crossed.

The line TR (T'R') is determined as a line from witch the clumping action of the reinforcement is taken into account. The line TR is determined after the examination of the experimental data, where point T is the middle point of the line OM.

If unloading starts from the primary curve between the load of first sliding (point L) and the maximum shear force (point M) and the maximum shear force in the direction of loading has not been exceeded, unloading follows a straight line from the load reversal point to a point of zero axial load (fig.6b). The slope of this line varies in a very short range. The main bearing mechanisms are shear friction in contact plain between floor slab and shear wall and the diagonal compression struts in the concrete. The change in stiffness of unloading line depends mainly on the descending value of shear friction coefficient. The distance between two points (L and M) is only 0,9 mm and for this short distance the descending of friction coefficient is very small to be taken into account. To simplify the model it is assumed the unloading to be with constant slope equal to the initial stiffness k_{so} .

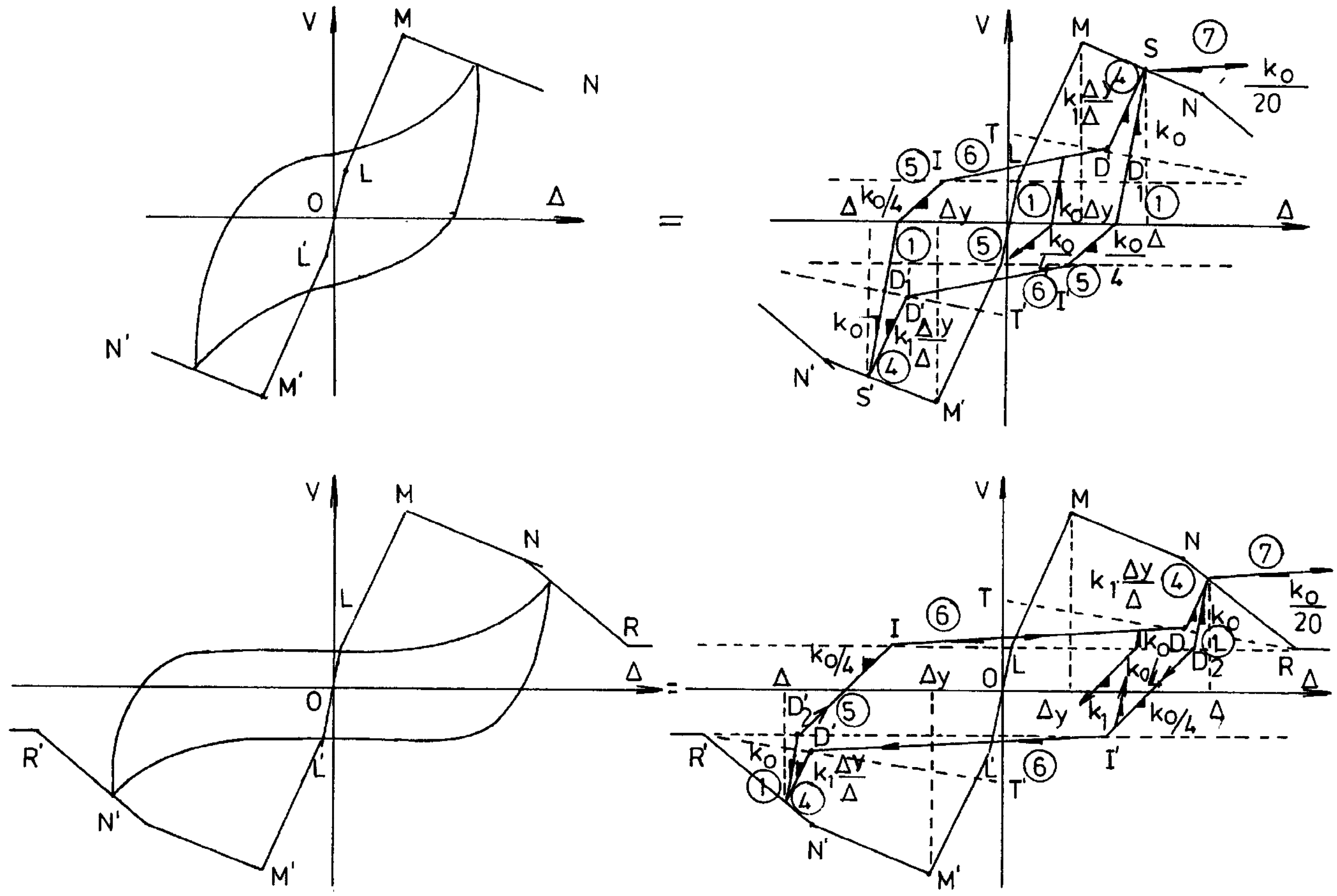

Fig.7.Segment of Proposed Hysteretic Model After Maximum Shear Force

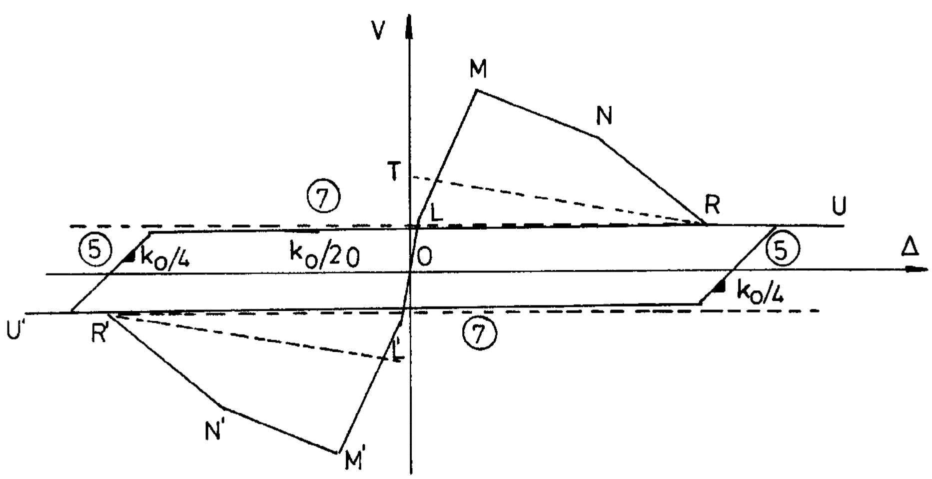

Fig.8. Segment of Proposed Hysteretic Model After Point R

If the maximum shear force is exceeded and the unloading starts between points M and N, up to a point of zero axial load the behavior is similar to that in the previous part (L-M). The main bearing mechanism are the shear friction in contact plane and simple friction in just destroyed connection. The deformations are small, as to cause considerable decrease in friction coefficient, as well as to involve the dowel action of the reinforcement (fig.7a).

After point N the connection is coming into the area of relative large displacements, where the changes in stiffness are significant. Experimentally it has been observed that the unloading curve changes its slope in the vicinity of point R (fig.7b). The part below the point R has lower stiffness than the part above. The statistic analysis of the experimental data shows that the relationship between the unloading slope and the displacement ductility can be expressed by a straight line. The rules for unloading in this part are as follows:
- unloading follows a straight line up to a horizontal line passing through point R. The stiffness in this part is commensurable with the initial stiffness k_{so}.
- after the horisontal line passing through point R, the unloading is a straight line with reduced stiffness equal to $k_{so}/4$.

Point R is considered as the end of the bearing area of the connection. The unloading after this point is similar to that in previous part (fig.8).

Loading and reloading

The first loading follows the primary curve, until unloading starts. If the unloading starts before point L, no hysteretic behavior is observed and loading in opposite direction and reloading follows the primary curve. If the sliding point (L) is exceeded, but the point of maximum shear force (M) is not, the loading and reloading branches are directed towards the point on the primary curve with maximum displacement reached to this time.

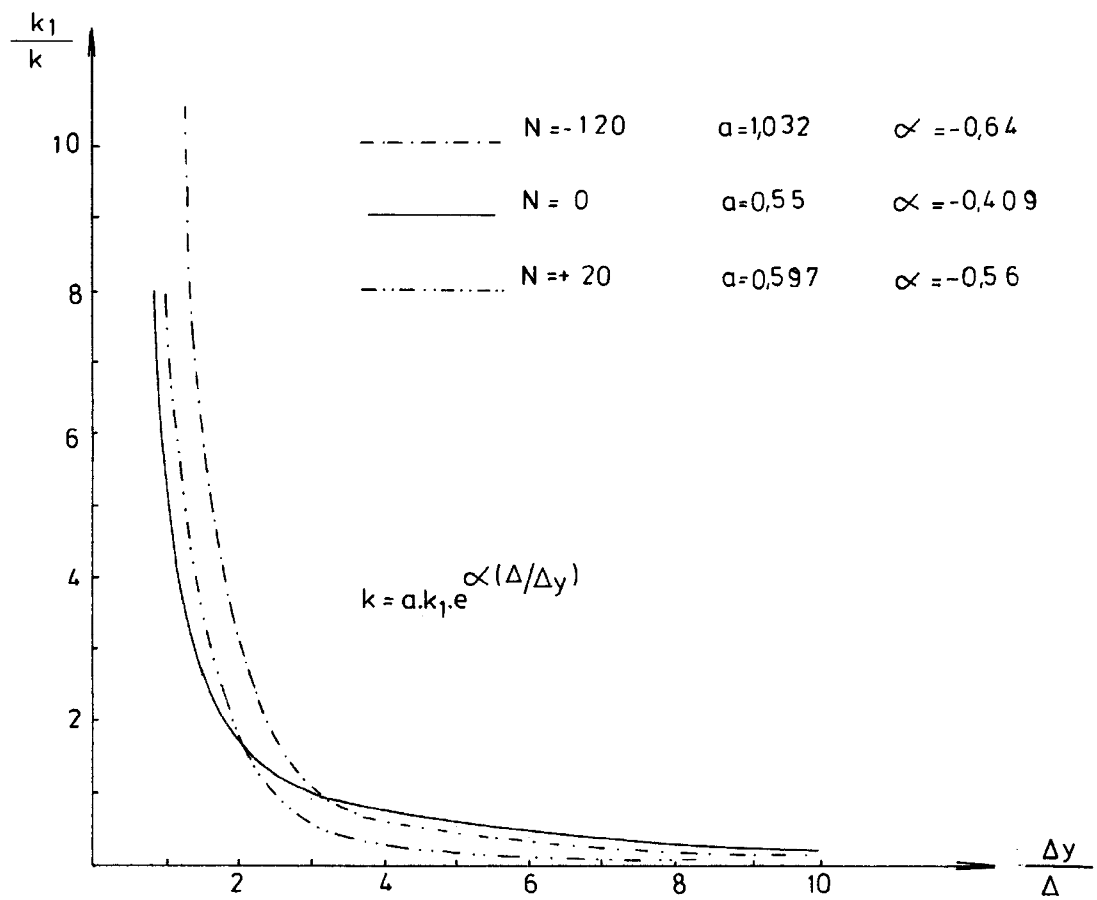

Fig.9. Variation of Stiffness Degradation with Ductility durin Reloading

Once the point of maximum shear force is exceeded, the response follows loading and reloading branches defined on the basis of experimental data. The shear force-shear deformation relationship has some specific characteristics.
One of the characteristics of the reinforced concrete elements is to display stiffness degradation under inelastic deformations. The element decrease its stiffness with the increase of magnitude of inelastic deformation or with the increase of the number of deformation cycles. The second characteristic is the

pinching effect, caused by sliding of two cracked surfaces, and is revealed by discending of stiffness by cyclic loading. In case of connections in prefabricated shear wall the pinching effect is followed by clamping action of the reinforcement and sudden increase of stiffness.
Another parameter that has significant effect on the character of hysteretic behavior is the axial load. Increase in axial load helps the fullness of the loops.

The slopes by reloading is defined ussing k_1 / k ratio. The variation of this ratio with the parameters having influence on it below line TR is given on fig 9.

SUMMARY AND CONCLUSIONS

The proposed hysteretic model was developed for the connection in prefabricated shear walls. The model consists of two part - primary curve and set of rules for branches of the hysteretic relationship. The model is for elements subjected to reversal shear and constant axial load (compression, zero and tension). Stiffness degradation,pinching and dowel action of the reinforcement are included in the model.

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