MODELLING OF RC WALLS UNDER SEISMIC ACTIONS

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Summary: *Main characteristics of behaviour of RC walls under seismic and/or dynamic (seismic) actions are presented in this paper. Behaviour of concrete and reinforcement steel is briefly described, and stress-deformation relations are also given. Historical development of models for analyzing the walls is presented, as well as typical concepts of response.*

Keywords: *Shear RC walls, constitutive relations, micro models, macro models*

1. INTRODUCTION

Reinforced concrete (RC) walls are very efficient for receive of lateral forces and have been widely used in the last several decades.
Their implementation is the easiest way to achieve necessary lateral stiffness, and to provide structural resistance to horizontal seismic forces and wind actions.
A number of experimental and analytical studies of behaviour of RC walls have been conducted for the purpose of predicting response under seismic actions [1].
Predicting the behaviour of RC walls under lateral loading requires advanced numerical models which are calibrated/verified by experimental testing [2].

2. CONSTITUTIVE MODELS OF MATERIALS

Concrete is a composite material which consists of: cement paste, aggregate and transit zone between aggregate and cement paste. By increasing the compression stresses in concrete irreversible deflections and failures occur, which eventually lead to brittle fracture.

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Behaviour of specimens subjected to uniaxial compression loading until the fracture occurs *f*c, can be presented with three typical states: low intensity of stress state, when deflection is mostly reversible and behaviour is considered as elastic ($\sigma<0{,}3\,f_c$).
By stress increment, micro cracks develop, behaviour is noticeably non-linear, followed by stiffness degradation and irreversible deflections.
When stress reaches fracture limit ($\sigma \approx f_c$), macro cracks are appeared joining together to form global discontinuities of specimens surface..
After reaching the fracture limit, behaviour is than characterized by the "softening" part of the curve, with sudden increment of deflections.
Tensile strength of concrete (f_{ct}) is a parameter which is difficult to obtain by direct experimental testing. Values are obtained by indirect testing (e.g. bending test or tearing – Brazilian test) [3].
Tension stress is linear up until the 80% of its maximum value. Maximum value of tension stress is considerably smaller compared to the maximum compression stress value (f_{ct} <20% f_c). Upon reaching the maximum value, crack is formed and resistance is reduced on very low residual value (figure 1-a).
Degradation of stiffness occurs under cyclic loading mostly because of spreading of micro cracks. Irreversible deformations are also present as a result of locking and slip phenomenon between the surfaces, which prevent closure of cracks [4]. When specimens are subjected to cyclic compression loading, the envelope of stress-strain curve corresponds to the curve of monotonous compression test [3], [5] (figure 1-b).

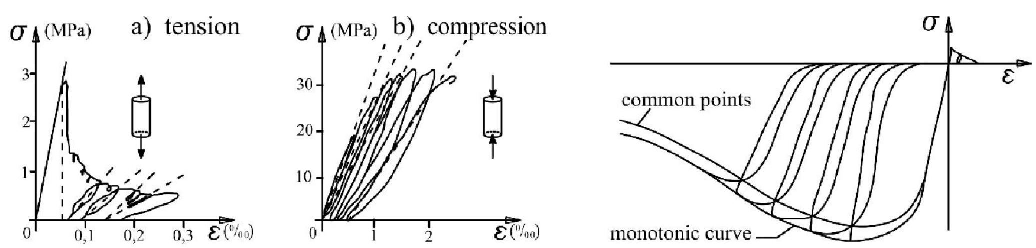

Figure 1. Cyclic tests on concrete specimens [4], Typical concrete response under cyclic loads [6]

Under alternative loading (from tension to compression and vice versa) the stiffness recuperation effect is noticed (figure 2), which depends on orientation and characteristics of micro cracks. RC walls are subjected to multi axial stress states.
Effect of shear stress on reduction of load bearing capacity of concrete (figure 2-b) is presented in the paper [7]. For biaxial stress state significant rise of shear bearing capacity of concrete occurs with the increase of normal compression stress and can reach 20% *f*c. This effect is less prominent with tension.
With biaxial stress state, the confinement effect can be achieved, which represents the passive resistance to lateral deflections due to Poisson's effect and has significant influence on stiffness and force distribution.
Confinement of cross-section can notably change the behaviour of concrete, not only regarding the load bearing capacity, but also ductility [8].

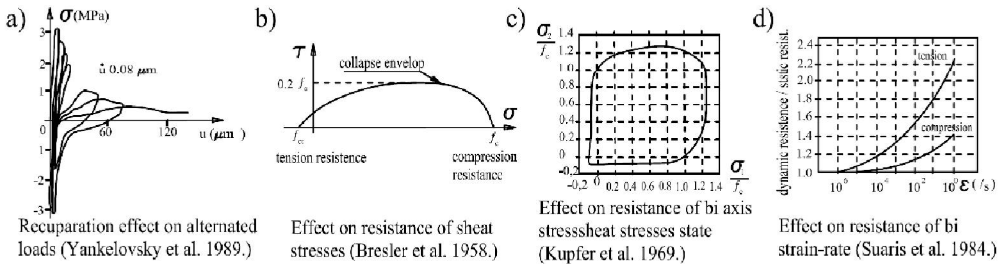

Figure 2. Effect of alternative loading, biaxial loading and load increment speed on load bearing capacity of concrete

Another important effect related to behaviour of RC structures during the earthquakes is load increment speed. When concrete specimens are tested with increasing velocity an increase of the maximum resistance is observed. That is, mostly, because of high sensitivity of micro cracks to the stress increment speed. Considering the fact that for typical earthquakes frequency ranges between 10^{-6}/s and 10^{-1}/s, dependence shown on (figure 2-d) indicates load capacity increment up to 80% for tension and 25% for compression [9].

Reinforcement steel is classified in two types: hot rolled and cold drawn, figure 3. Cold processed steel has higher bearing capacity but lower ductility. If cross-section is confined and no buckling occurs, behaviour at tension and compression is similar. After subjecting to alternative cyclic loading steel manifests non-linear response (Bauchinger's effect). Another important phenomenon is cyclic strengthening which manifests in increment of load bearing capacity of steel during the later cycles (figure 3-b). There are several models of steel behaviour, among which are most widely used: elastoplastic model, bilinear model and multilinear model [10]. During the earthquakes RC walls dissipate seismic energy by non-elastic deflections, whereby bond between concrete and steel is highly tensioned and results with: bond failure, forming of cracks, stiffness fall and degradation of cross-section. Bond between reinforcement bar and concrete is a results of: chemical adhesion between steel and cement paste, mechanical resistance associated to the ribs (shear in the concrete between ribs and the compression struts). Upon bond skidding, different elongation in steel and concrete occurs which leads to relative displacement (figure 3-c).

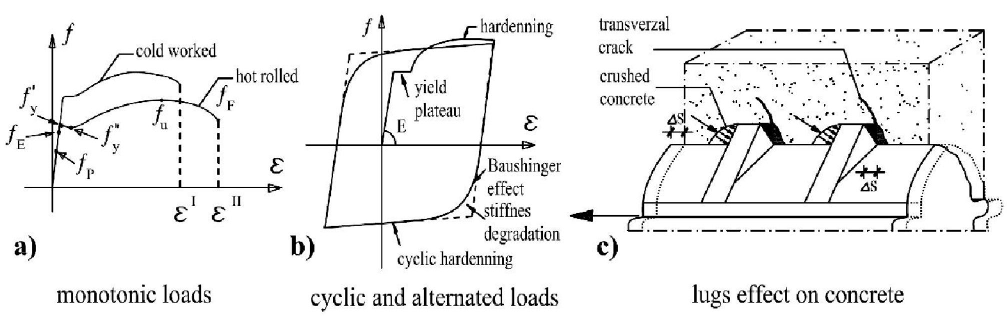

Figure 3. Behaviour of reinforcing steel

3. MODELING OF RC WALLS

Models of RC walls under dynamic actions should comprise most of the factors which influence their behaviour, such as: creep of reinforcement steel, grinding of concrete, buckling of reinforcement steel, stiffness reduction, occurrence of residual deflections, skidding of wall, interlock effect of aggregate, effect of multi-axial stress state in concrete, effect of stress increment speed etc. Different techniques of modelling RC walls are presented in the paper, starting from the most simple macro models, combined models, to the micro models such as finite element models and fibre models.
Macro models (global response models) are based on global hysteresis behaviour of RC walls, which is defined by dependence moment–rotation or force–displacement [13]. With the development of fibber models, member model, truss model and vertical axial springs model [1],[2] are no longer being used. Macro models are very efficient and can successfully simulate response of element subjected to axial force and bending moment about one axis (important for RC walls). For biaxial bending, it is much more difficult to define model, because hysteresis dependences are very complex, especially for alternative cyclic loading (typical for the columns) [13].

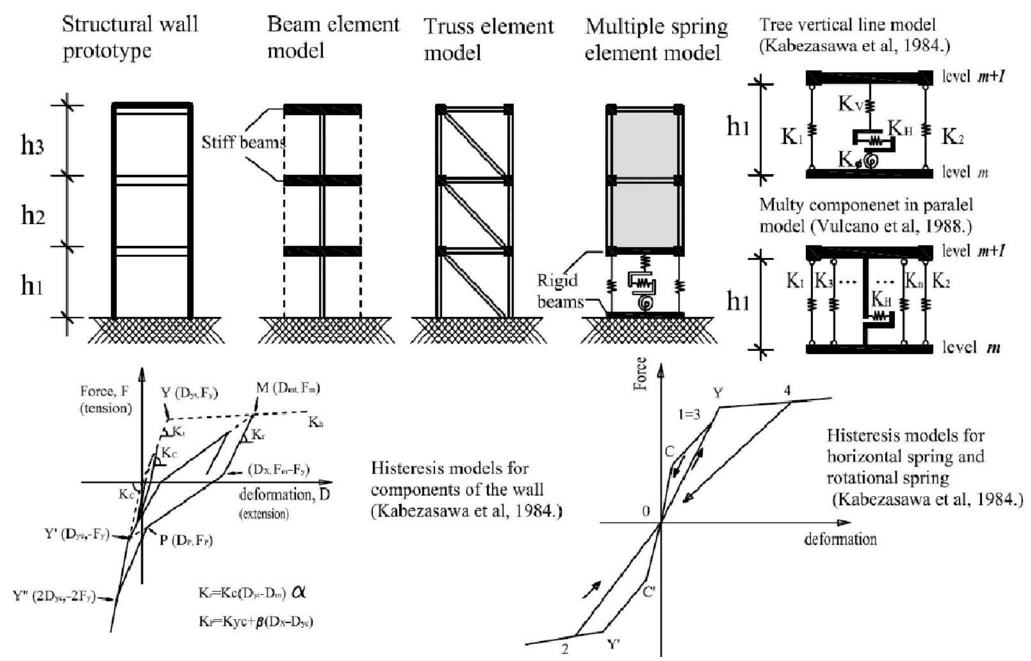

Figure 4. Macro models and hysteresis of RC wall behaviour [12]

Fibre micro models are presently very common way of modelling in seismic engineering. Their advantage is ability to efficiently simulate biaxial bending, while disadvantages are inability to directly simulate shearing and yielding of steel – concrete bond. They are convenient for columns, which have bending as dominant stress state, and should not be used for walls, especially short ones. Combined with strut-and-tie models they can simulate shearing of walls.

Most general technique for modelling RC walls using micro models are finite elements. Modelling of reinforcement steel can be done in two ways: discrete model and "smeared" model. For discrete model density of mesh must directly correspond to distance of reinforcement bars. It requires elaboration of mesh in advance, and it sometimes can be robust. Grouping few reinforcement bars into one element resulted in model of smeared reinforcement (figure 5-d) forming continuous layer of steel separately for each direction (multi layer shell). Non-linear behaviour of RC mostly originates from creep of reinforcement steel, tension in concrete and emergence of cracks. There are two approaches in cracks modelling: discrete cracks approach and "smeared" cracks approach. Second approach is more common and it does not simulate individual cracks, but all the cracks on an element are simulated with fictional "smeared" crack. Modelling with spread reinforcement steel and cracks is common and provides good matching with experimental results.

Modelling by discrete method is effective if reinforcement bars are with bigger diameter and also grouped. 3D models with solid finite elements still have not found a wide use in non-linear dynamic analysis because of complex formulation and big computer requirements. Possibilities of this method are wide, and it is able to simulate most of the phenomenon related to behaviour of concrete under dynamic actions. Non-linear solid 3D models are currently being used for analysis of joints, characteristic details, and individual structural elements.

They are rarely being used for dynamic analysis of bigger systems, because of the complexity and robustness of problem. There are three concepts for modelling the reinforcement steel: "spread" reinforcement, where particular reinforcement percentage is applied for each direction; discrete method with link elements capable of transferring only axial loading with the possibility of plasticization (this type is used most frequently) and solid volume elements (figure 5-e). Interaction between elements which represent concrete and reinforcement steel is most frequently resolved by simple connection between the elements in joints. More advanced models treat this phenomenon as a contact problem, which significantly complicates calculation.

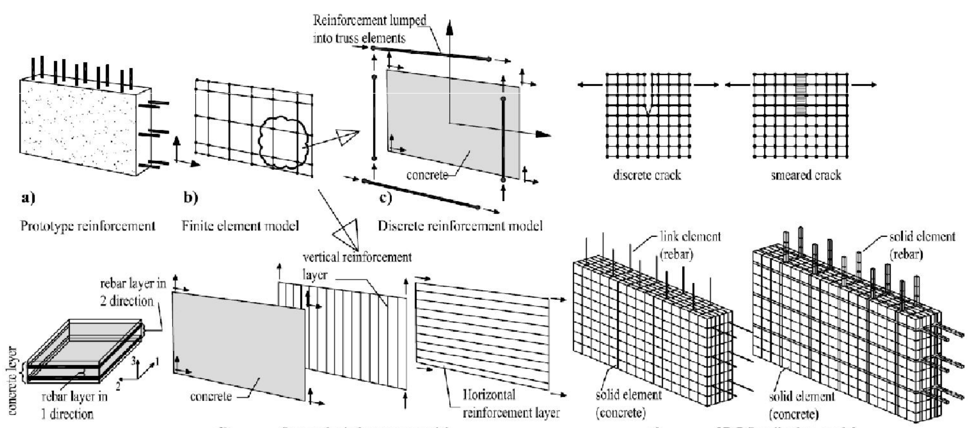

Figure 5. Basic types of micromodels of RC walls specimens

4. CONCLUSION

Development of most important model for non-linear analysis of RC walls under dynamic actions is briefly presented in this paper. It is required from models based on principles of micro and macro modelling to comprise as many factors which have influence on behaviour of RC walls, but on the other side remain simple enough to provide non-linear time analysis (time history analysis). Based on everything presented the following can be concluded: For micro models for simulating response of concrete, spread cracks approach has the advantage over the discrete cracks model; Macro models efficiently simulate response of RC walls, Fiber models are used for most of 3D analysis, but cannot simulate some of the most important phenomena. 3D models composed of solid finite elements are still not widely used because of disadvantages, such as complexity and robustness.

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МОДЕЛИРАЊЕ АБ ЗИДОВА НА СЕИЗМИЧКА ДЕЈСТВА

Резиме: *У раду су приказане основне карактеристике понашања АБ зидова под сеизмичким и/или динамичким (сеизмичким) дејством. Сажето је описано понашања бетона и арматуре и дате су везе напона и деформацција. Презентован је историјски развој модела за анализу зидова и типичне концепције одговора.*

Кључне речи: *Смичући АБ зидови, конститутивне релације, микро и макро модели*