Pakistan Journal of Applied Sciences 2(3): 346-350, 2002

A Numerical - Experimental Study of Design Parameters for Anchoring Rebar in Rehabilitated Concrete Structures

[1]Oussama Baalbaki, [2]Khalil Elawadly and [2]Ahmed Ellakany,
[1]Beirut Arab University; [2]Alexandria University, Lebanon

Abstract: Anchoring of reinforcing bar in concrete structural members is widely used in rehabilitation or structural repair. Also, addition of new structural elements made on existing structures constitutes an important aspect for use of anchors. The objective of this publication is to study the effect of some design parameters required to calculate the allowable load capacity for anchoring systems. The mechanical performance was determined experimentally under pull out loading. A numerical model based on finite element was used to study the effect of anchoring parameters such as embedded depth of the anchored rebar, bar diameters, concrete and epoxy strength on the behavior of the anchoring system. The experimental and numerical results show that the tension capacity of the adhesive anchor is increased with deeper embedment depending on the bar diameter. The design load should be the less of the allowable working load of either ultimate bond strength or the yield strength of the rebar. Critical application such as dynamic loading and combined pull out and shear loading should be performed to determine the exact factor of safety required for the design.

Keywords: Structural Repair, Anchored Rebar, Concrete Structure

Introduction

The placement of fresh concrete against existing hardened concrete has been gaining importance as a result of the increasing need of rehabilitation and strengthening of existing structures. The main anchoring systems used in normal weight concrete and masonry unit are the mechanical and chemical anchors. There are many applications of anchoring rebar in building construction, which includes concrete remedial works or structural upgrading and repair, extension of columns, beams, walls and slab connections.The transfer of internal stresses across the bond interface between the new and the old concrete is a critical aspect should be considered in any design approach.

The shear resistance of the reinforcement is shared with the mechanism of cohesion and friction (Sujivorakul *et al.,* 2000), (Abrishami and Mitchell, 1996), (Arbor). At the present time, there is a need to provide engineering design concept and standardized regulations for safe and economical anchoring different than that generally provided by the manufacturers (Fasting Technology Manual, 1998), (UEAtc Directives, 1986). Testing methods should be developed for each application to allow a progress in engineering design and to determine the permissible loading capacity based on several safety factors and different influencing factors. This paper presents a parametric study of design parameters for anchoring rebar in rehabilitated concrete structures such as the adhesive epoxy material, embedment depth and diameter of rebar, and the strength of concrete structure.

Experimental Program

Setting of rebar in concrete: The hole is drilled to the specified depth and diameter, cleaned and brushed to ensure perfect bonding of the adhesive material. Then the hole is filled by the adhesive and the reinforcement bar is inserted. The adhesive bond material is based on two components consisting of resin and hardener. The polymerization reaction ensures good bonding and rapid curing. As a result of the above steps a strong bond between rebar and concrete similar to that cast in site is achieved.

Materials and Methods

Concrete blocks of 100x100x45 cm dimensions are prepared following ACI code calculation of the mixture proportion. The edge and spacing distance between the reinforcing bars are 25 cm. Therefore, nine tests per block can be performed. Grade 60 reinforcing deformed bars according to ASTM A615 are used. An epoxy two components adhesive material is used as a non-shrink anchor grouting material.

Pull out testing procedure: A hydraulic test unit is used for applying pull out load. The test data obtained are performed base on ASTM standard E 488 (ASTM) for strength of anchors in concrete and masonry elements. A hydraulic test assembly set is used for

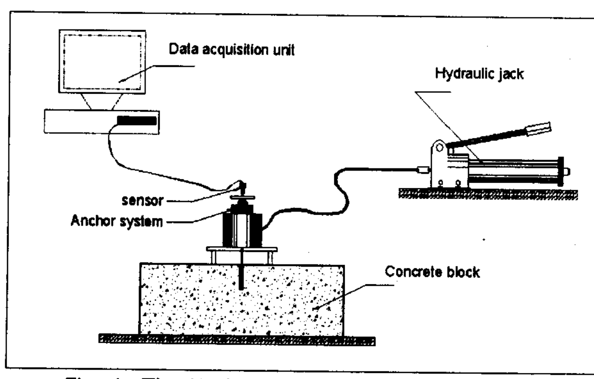


Fig. 1: The Hydraulic Pull Out Test Set Up

applying a static pull out test as shown in Fig. 1.

The rebar passes through a hollow hydraulic cylinder and fixed with an anchoring system.

The cylinder is resting on a frame to avoid the test area from loading reaction. The load is applied gradually in an axial direction to the rebar by a hydraulic pressure jack connected to the cylinder. An electronic sensor related to data acquisition unit is used to measure the rebar displacement and a load gauge measure the load capacity. The ultimate load measured is the load that causes the failure. There are different modes of failure depending on loading conditions, geometrical parameters and characteristics of steel, concrete and adhesive material. The main patterns are splitting or concrete break out with conchoidal area, steel failure and rebar pull out. Generally, the manufacturer of the adhesive material provides the diameter of the hole and the embedment. The whole diameter and embedment depth are taken approximately as 1.2 and 12 times the rebar diameter (Ø). Pull out tests are performed on the following rebar diameters and the ultimate loads are registered at anchors failure, Table 1.

Table 1: Loads Registered at Anchors Failure

Rebar size (mm)	Ø 10	Ø 12	Ø 14	Ø 16	Ø 20	Ø 25
Hole diameter (mm)	12	15	18	20	25	30
Embedment Depth (mm) L= 12 Φ	120	144	168	192	240	300

Numerical Model

Finite Element Analysis: The finite element method (FEM) is recognized by developers and users as one of the most powerful numerical analysis tools ever devised to analyze complex problems of engineering. The method is endowed with two basic features, which attribute to its success: First, a geometrically irregular domain is envisioned as an assemblage of simple subdomains, called finite elements. Second, over each finite element the quantities of interest (displacements, stresses, etc.) are approximated using element-wise continuous functions which are easy to evaluate on a digital computer. Computer implementation of the method is modular, and allows general-purpose code development with different types of elements and degrees of approximation.

The analysis was performed using the general-purpose finite element computer program ANSYS (1996). This program contains a variety of elements for the analysis of practical problems, and postprocessors that can give, for example, stress and deflection contours as functions of position.

Description of the Numerical Model: The model chosen for the analysis is a concrete block of 50×50×45 cm. The edge and spacing distance between the reinforcing bars are 25 cm exactly the same as the experimental test. The length of the embedment depth of the steel bar is varied from 12 Φ for the case of long bar test to 8 Φ for the case of the short bar test, where Φ is the diameter of the steel bar. The diameter of the hole is taken as 1.2 the diameter of the bar. The material properties (concrete, epoxy and rebar mechanical properties) and the testing loads are the same as in the experimental part. Because of the symmetery, we choose one cell contains only one steel bar as shown in Fig. 2. The boundary condition at the edges of the concrete cell are selected to satisfy the actual response of the whole block. A complete picture for the behavior of the cell is obtained by calculating the stresses and the displacements in both x and y-directions at each point which is the main advantage of the numerical model. Fig. 3 and 4 show the stresses distribution in both x and y-directions (MX represents the maximum stress & MN represents the minimum stress), the maximum stress in y-direction appeared at the top of the steel bar. It is obvious from the stress contour in x-direction that the failure should occur at the cone which appeared at the top of the concrete part.

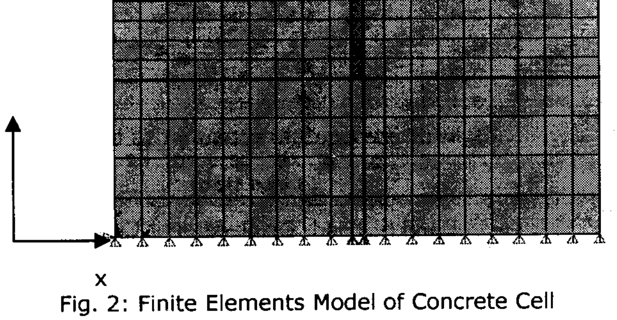


Fig. 2: Finite Elements Model of Concrete Cell

Numerical and Experimental Comparison

Load Displacement Behavior: The load displacement (in Y direction) behavior for some diameters were plotted while performing pull out tests. Knowing that the load behavior for rebar is different than for concrete, the load behavior obtained represents the system of base material and rebar. We are interested in our comparison in the elastic zone where the system does not undergo a large deformation which occurs before failure. The behavior of the system was also predicted using ANSYS program. Higher displacement values were found in the experimental curves Fig. 5 a&b. This was due to the fact that the measurment were performed at a distance from the breaking point.
Knowing that large displacement occurs in the necking zone, therefore, the measured value represénts the cumulated displacement value. While the maximum displacement for the model represents the localized displacement at the breaking point. It is clear that the displacement is increased by the use of smaller diameter.

Ultimate Load Capacity: A comparison was made between the ultimate load for each rebar diameter obtained experimentaly and from the numerical model based the failure tensile and tension stress in concrete (30 bars) Fig. 6, where the numerical values were deduced from Fig. 10. We consider that the failure occurs at the begining of cracks formation in concrete and achieved at the breaking of the rebar. This will enhance the validation of the proposed model.

Factors Influencing Anchors

Influence of Concrete Strength: The ultimate loads were determined on two series of blocks having two different compressive strength (40 & 17 Mpa). The maximum stresses were also obtained from numerical model for all influencing parameters at the same tesile Load (15 ton), geometrical data and mechanical properties.The results obtained show that for both numerical and experimental results the load / stress increases with the development of strength Fig. 7 a & b. For different compressive strength, a concrete influencing factor can be determined corresponding to the recommended design load. The ultimate load increases as the diameter is increased. while, the maximum stresses decreases with the increase of the bar diameter.

Influence of embedment depth: A very important factor influencing the load bearing capacity is the embedment depth of the rebar. The load capacity is determined at spcified depths (L=12 Ø for long bar & L=8 Ø for short bar). The resultant forces transmitted across the interface of the rebar are taken up by the concrete base material. This means, a greater volume of the base material is acting as the depth increases. There is a positive effect of greater anchoring depth if the mode of failure is a break out of concrete. However, the increase in the ultimate load or the decrease in the maximum stress is limited by the strength of the rebar and the friction resistance at the interface. The load capacity of the anchor is increased as the depth of embedment increases Fig. 8 a&b. However, after a specified depth, the load bearing capacity may no longer increase because of the local destruction of the concrete. The depth of embedment is also influenced by the direction of loading.

Influence of Adhesive Material: By setting the same parameters and varying the adhesive strength material properties (Low strength epoxy was taken 75 % of High strength epoxy), we notice a slight decrease in the stresses using the model Fig. 9. There was no experimental data for comparison but, the same conclusion would be expected.

Load Design Parameters: The ANSYS Program allows analysis of the different design parameters and to plot the characteristic curves for different rebar diameter. The applied tensile load varies from 5 to 25 tons for each bar diameter. Fig. 10 a&b illustrates the maximum stresses in x (concrete) and y direction (steel bar). These curves can be used to determine the specified bar diameter and embedment depth related to a required load design or to assign for a specified load, the suitable bar diameter and depth. By using different embedment depths for the same design load, the results obtained allow to plot generalized curves for predicting the maximum stresses as shown in Fig. 11 a&b. From these curves, it is possible to select the design parameters (embedment depth and bar diameter). We note that the maximum failure stresses must be defined.

Other Influencing Factors: There are many other parameters beside the depth and bar diameter that need to be taken into consideration in the model such as the spacing between anchors and the edge distance. The critical spacing distance is the distance at which the concrete breaks without influencing the neighboring anchor. The minimum edge distance between anchors and concrete block edge is the distance where the concrete volume required to take up the forces is not reduced. The reinforcement of concrete has a positive influence to resist concrete breaking.The design tensile force results from the characteristic strength of the steel, the adhesive bond (rebar-adhesive material) that increases linearly with the anchorage length and concrete bond (concrete-adhesive material). Generally, the safety level of the design load is verified by comparing the designed load to the resistance of anchors. The actual applied load should be equal to or less than the recommended load calculated based on safety factors. The influence of type and direction of loading has to be considered.

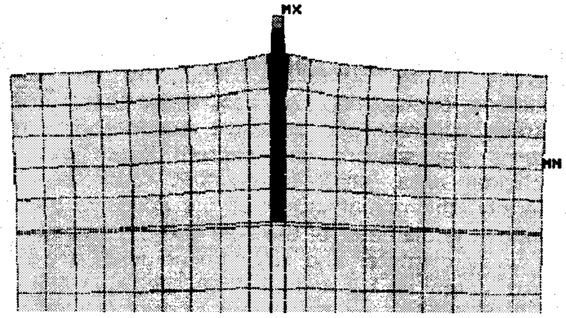


Fig. 3: The Stress Distribution in the Y-Direction For The Case Of Long Steel Bar Test (Load=25 Tons)
Note: (MX: Maximum Stress, MN Min Stress)

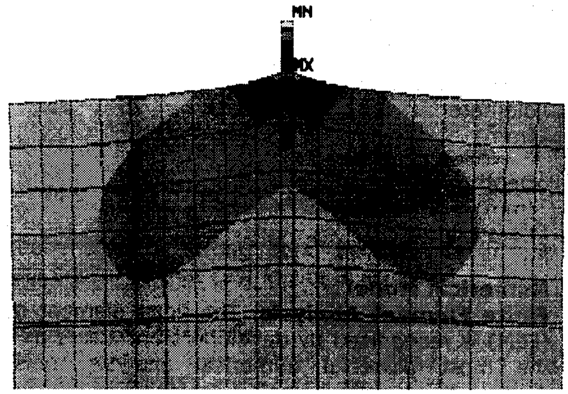


Fig. 4: The Stress Distribution in the X-Direction For the Case Of Long Steel Bar Test (Load=25 Tons)
Note: (MX: Maximum Stress, MN Min Stress)

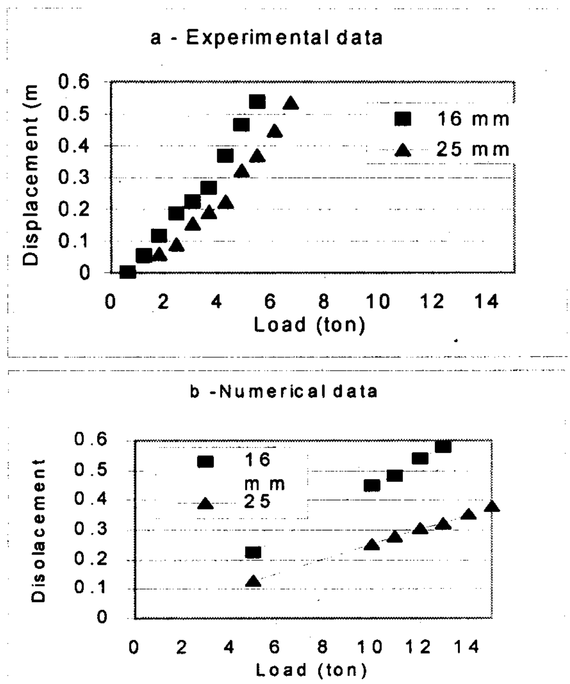


Fig. 5a and b: Load- Displacement Curves

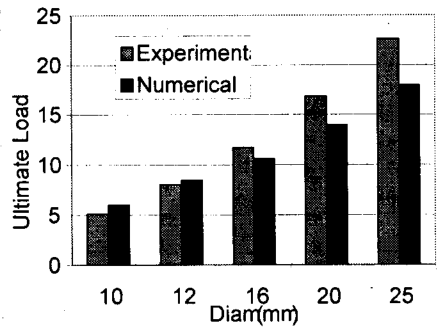
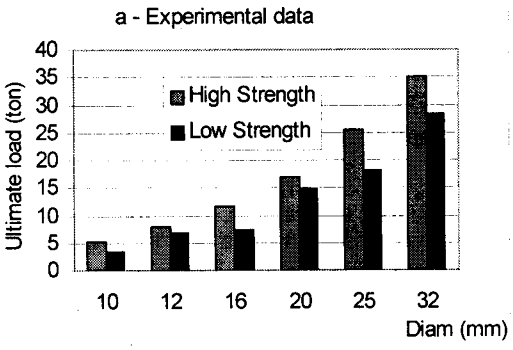


Fig. 6: Ultimate Load Capacity Comparison



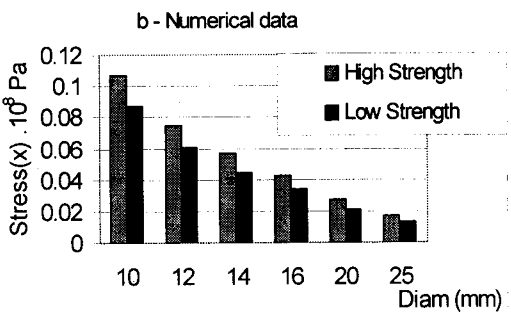
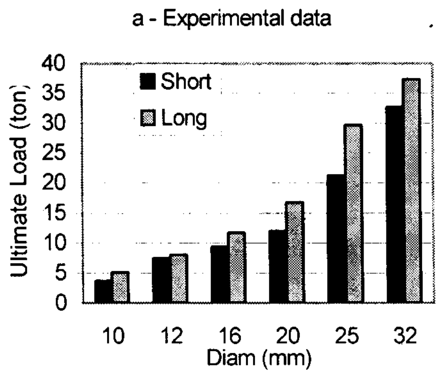


Fig. 7a and b: Influence of Concrete Strength



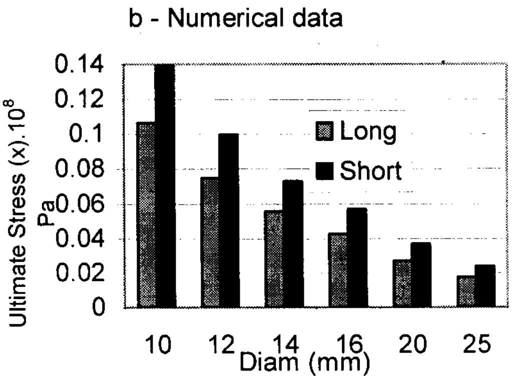


Fig. 8a and b: Influence of Embedment Depth

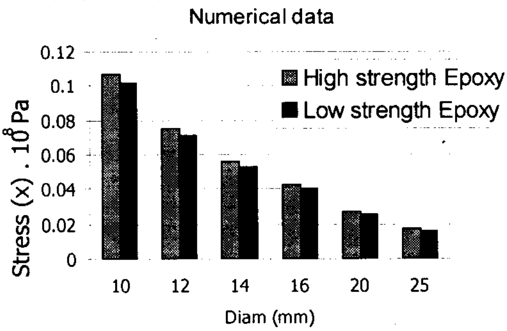


Fig. 9: Influence of Adhesive Strength Material

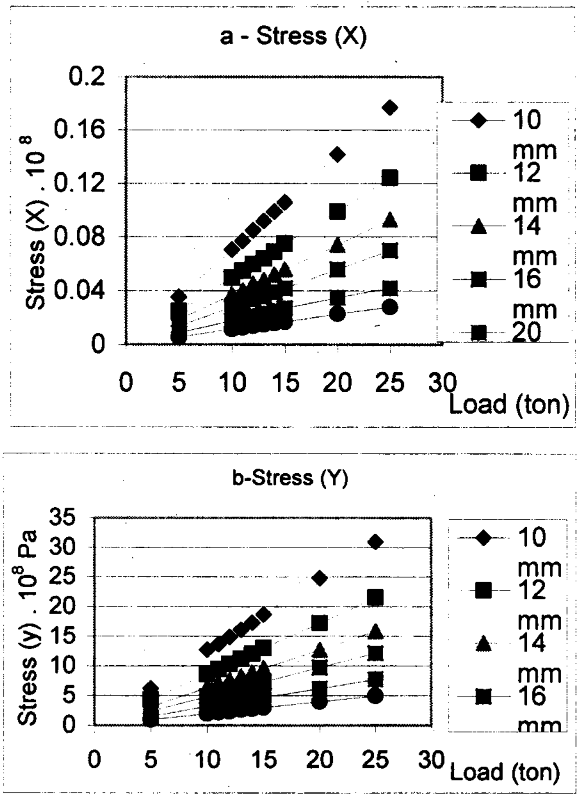


Fig. 10a and b: Tensile Load versus Stress (X) and (Y)

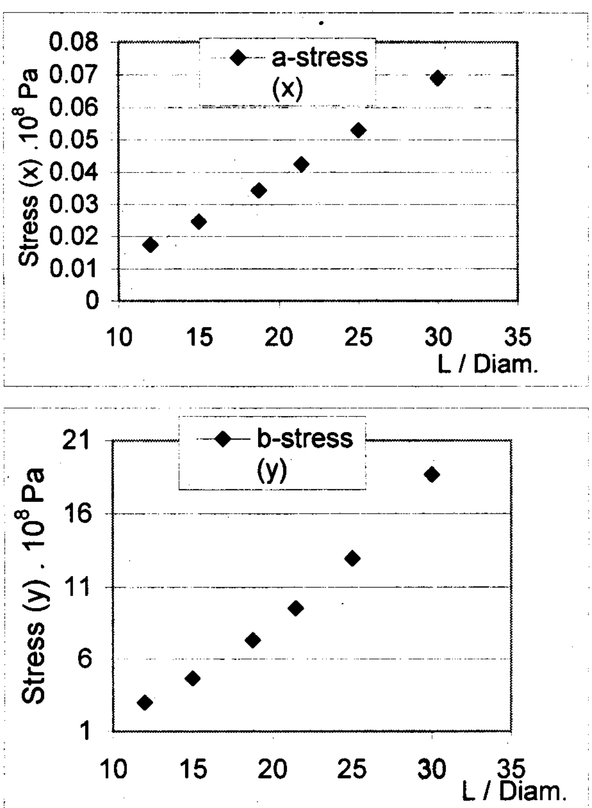


Fig. 11a and b: L/D Ratio Versus Stress (X) and (Y)

Conclusion

The design and installation of rebar must be carried out with great care based on standard engineering practice and technical data to make sure that the level of safety is guaranteed,(CEM Guide), (CEB Comite, 1992). The basis for anchoring design is based on the recommended value obtained on a special concrete strength and geometrical conditions (depth, spacing and edge distance). The goal of this publication was to study some influencing factors on anchoring rebar in concrete structures in order to provide a design approach. The allowable tension load must be the lesser than the allowable steel strength. As a result, when designing anchors, the types of loading, the base material and the geometric conditions must be analyzed and the corresponding influencing factors are then applied. Research has to be done on different types of loading. Dynamic, combined shear and tension, seismic loads are beyond this report. The safety concept in those cases should be different than in case of static loads. Due to the lack of international guidelines, the anchoring design will be governed by approvals based on testing procedures (ICBO, 1999).

References

ASTM E 488-96. Standard test methods for strength of Anchors in concrete and masonry elements.

ANSYS, 1996. User's Manual, Swanson Corp., CA, U.S.A.

Ann Arbor, "Bond stress-slip mechanism in high performance fiberreinforced cement composite.", Ph.D. Thesis, Uni. Michigan.

C. Sujivorakul, A.Waas and A. Naaman, 2002. "Pullout Response of Smooth Fiber with and End Anchorage",J. Engineering Mechanics.

CEB guide, Design of fastening in concrete.

CEB, 1992. Comité Euro-International du Béton: "Fastening to reinforced concrete and masonry structures" ACI special publication SP 130.

Fastening Technology Manual of HILTI 2/98

H. Abrishami, D. Mitchell, 1996. "Analysis of bond stress distributions in pullout specimens." J. Struct. Eng, ASCE.

ICBO, 1996. Evaluation Report ER 5560.

UEAtc, 1986. Directives for Assessment of Anchors, UEAtc.