

Analysis of High Strength Friction Grip Bolted Shear Connectors in Composite Beam Section

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ABSTRACT: Composite beams comprised of concrete slabs and steel beams are joined by mechanical shear connectors are commonly used in modern building design. The use of innovative deconstructable high-strength bolt shear connectors shows higher capacity and ultimate strength than that of conventional headed stud connectors. This paper describes the modelling and analysis of three dimensional finite element model of push out test specimen of composite beam with M22 8.8 high strength bolted connections. The modelling and analysis of the specimen was completed in finite element analysis software called ANSYS Work bench 16.1. An extensive parametric study was conducted on this FE model to investigate the effect on ultimate shear strength and the load-slip behaviour. The effects of the change in the bolt diameter, bolt pretension, its clearance between the hole in the concrete slab, bolt tensile strength, number of bolted connection and the pitch of bolt are elucidated through parametric studies.

KEYWORDS: Composite beams, Friction-grip bolt, Push-out test, Finite element model, ultimate shear strength

I. INTRODUCTION

Composite steel structures formed by connecting the concrete slabs to the supporting steel beams have been widely used for many years throughout the world. Composite action between steel beams and concrete slabs through the use of shear connectors is responsible for a considerable increase in the load-bearing capacity and stiffness of the steel beams, which when utilized in design, can result in significant savings in steel weight and construction cost. The capacity of the shear connection to transfer longitudinal shear forces depends on the strength and stiffness of the shear connectors. Push-out test is the most common way to evaluate the shear strength and behaviour of shear connectors. A push-out specimen consisted of two identical reinforced concrete slabs attached to the flanges of a short steel wide flange section by means of shear connectors.

Xinpei Liu Mark A. Bradford et al [1] done a comparative study of experimental push out test of composite beam connected by bolted connector with the finite element analysis. Parametric study was conducted to investigate the behaviour of bolted connector with various parameters such as bolt diameter, bolt pretension, tensile strength of bolt and compressive strength of geo polymer concrete slab. He found good agreement with push out test and the finite element analysis done in ABAQUS software. Ali Shariati et al [2] reviewed various types of shear connector in composite structures. This review tries to identify the shear connectors that are most relevant to composite structures. A comparative study of various types of shear connectors, their advantages, disadvantages and the most efficient type of shear connector was revealed in it. Christine Heistermann [3] developed four different bolt types with respect to the ease of installation and maintenance. Various influences on the reduction of clamping force are experimentally checked, such as the type and thickness of coating, the thickness of the clamping package and external loading. He concluded that a coating on the surfaces of the jointed plates increases the loss of pretension, which means that the losses of pretension over time can be quantified depending on the number of coated plate surfaces. Marko S. Pavlovic [4] examined the longitudinal shear connection of composite decks by considering requirements for application, technical aspects, cost effectiveness and environmental impacts. Failure modes of bolted shear connectors with single embedded nut are recognized as failure of the bolt at the flange-concrete interface and pry out failure of the

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concrete both in experimental and FEA results.

The work in this paper follows Modelling and analysis and parametric study. The main aim of this work is to analyse the behaviour of bolted shear connection in composite beam for various parameters and to study the effect of various parameters on ultimate shear resistance and load slip behaviour of the composite beam.

Paper is organized as follows. Section II describes the modelling and analysis of the FEM of the push out test specimen. Section III gives the results and discussion. Section IV presents conclusion.

II. MODELLING AND ANALYSIS

Fig. 1(a) shows the arrangement of the push tests specimen used to model FE model to determine the shear resistances and the load-slip behavior of HSFGB shear connectors in composite beam with precast concrete slabs. The model consist of an IS WB 350 steel beam and two concrete slabs that are 450-mm long, 500-mm wide and 100-mm thick attached to the flanges of the steel beam and reinforcement mesh having 10 mm diameter wire and 200 mm pitch were cast in the concrete slabs in two layers to limit the splitting of the slabs. M22 8.8 high strength friction grip bolt was used. The unit weight of steel is 7850 Kg/m^3 , modulus of elasticity is $2.0 \times 10^5 \text{ N/mm}^2$ and the poisson's ratio is 0.3. 390 Mpa, 500 Mpa and 830 Mpa are tensile strength of I section, reinforcement bar and the high strength bolt respectively. The density of concrete is taken as 2400 kg/m^3 . The short-term modulus of elasticity of concrete is taken as 31622.78 Mpa.

A. Boundary Condition and Contact Interactions

To eliminate any horizontal resistance being imposed by the slabs, a roller support was inserted at one end of the specimen. Other end was taken as fixed. The model consists of many contact surfaces. A friction coefficient equal to 0.45 was used for the contact interaction between the steel and concrete components, while the friction coefficient was taken as 0.25 for all of the other interactions [5]. Half of the specimen was modelled and analysed due to the symmetry.

B. Preloading and Loading

The preload is given by using the BOLT PRELOAD function available in work bench 16.1. All specimens, except for those with preload as a changing parameter and for diameter changed parametric study, 173 kN preload were applied. Uniformly distributed load was applied on the top of the steel beam section in order to ensure the shear on both sides of the steel beam. In push out testing procedure the load is applied on the top of the steel section. The load range is depends upon the capacity of the loading instrument. The same load was applied in ANSYS. 50 mm triangular meshing was used and the automatic controlled meshing available in ANSYS was used for doing the meshing. Fig. 1(b) shows the specimen with applied preload. The preload was applied to the cylindrical surface of the high strength friction grip bolted connection by BOLT PRELOAD option available in ANSYS software. And Fig. 1(c) shows the vertically down ward application of load to the cross-section of the steel I beam; the loading was done same as that of the push out test procedures.

C. Selected Parameters

The first parametric study was change in diameter of bolt. 5 different diameters are selected they are 18mm, 20mm, 22mm, 24mm and 25 mm. The hole clearance (4mm), bolt preload (95 kN) and tensile strength of bolt (830 Mpa) were taken as constant for all the 5 models. The diameter of bolted connection was selected according to IS 1367 (part 3): 2002, ISO 898 -1:1999 code for technical supply condition for threaded steel fasteners.

The secondly changed parameter was bolt pretension. 50 kN, 75 kN, 100 kN, 120 kN, 145 kN and 173 kN pretension forces were selected. The diameter of bolt (22mm), hole clearance (4 mm) and the tensile strength of bolt (830 Mpa) were kept constant for the 6 models. The preload force was selected according to the ASTM classification.

Third parameter was the tensile strength of bolt. 4 different tensile strengths such as 830 MPa, 900 MPa, 1040 MPa and 1220 MPa were selected for the study. For this analysis the diameter of bolt (22mm), bolt preload (173 kN) and hole clearance (4mm) were taken as constant. The tensile strength of 22 mm diameter bolted connection was selected from IS 1367 (part 3): 2002, ISO 898 -1:1999 code for technical supply condition for threaded steel fasteners.

The change in hole clearance of the diameter of bolt and diameter of hole in the concrete slab was taken as the fourth parameter. 0mm, 2mm, 4mm, 6mm and 8mm hole clearances were selected. The diameter of bolt (22mm), bolt

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pretension (173 kN) and the tensile strength of bolt (830MPa) were kept constant for the 5 FE models. The hole clearances were selected according to IS 4000 – 1992.

To study the effect on ultimate shear strength and load slip behaviour when the pitch of bolted connection was changed number of bolted connection was increased and 4 different pitches they are 55mm, 75mm, 125mm and 150mm were selected. The diameter of bolt (22mm), hole clearance (4mm), bolt preload (173 kN) and tensile strength of bolt (830MPa) were kept constant.

The analysis was done in ANSYS software, the effect of above mentioned parameters on the ultimate shear strength and load slip responses were examined separately for bolt at fixed support and at the roller support.

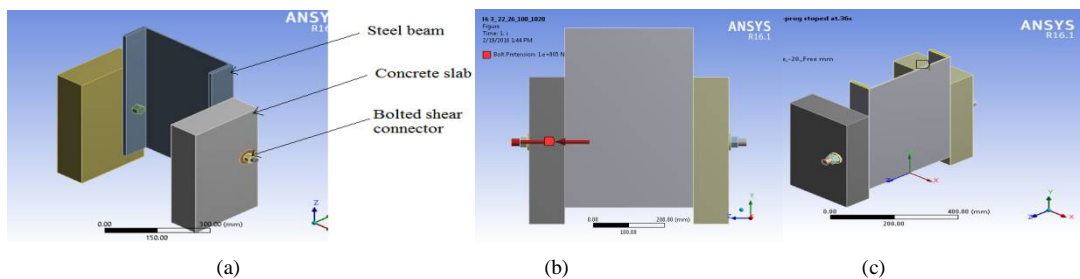


Fig. 1. Modelling and Analysis (a) FE model (b) Preloading of bolt (c) Loading of specimen

III RESULTS AND DISCUSSION

A. Effect of change in diameter of bolt

The critical slip of the bolted connection is 4 mm for bolt with 4 mm hole clearance. When the bolt diameter was increased from 18 mm to 25 mm the load at critical slip of the bolt at fixed end support was increased 3.62%. Similarly, for the bolt at the roller support, the maximum increase in load at critical slip was up to 3.172%. The load corresponding to critical slip was not much affected by varying the bolt diameter. Because, here the applied preload is constant. When the bolt diameter was increased from 18 mm to 25 mm the ultimate shear connection resistance of the bolt at fixed end support was increased up to a maximum of 51.12%. Similarly, for the bolt at the roller support, the maximum increase in ultimate shear resistance was up to 56.02 %. The main reason for increase in the ultimate shear strength of the bolt is the increase in the diameter of the bolted connection. When the bolt diameter was increased the energy absorption of bolt was increased as 89.81 % at the fixed support and 75.96 % at the roller support. When the diameter of bolt increases the energy absorption capacity of bolt also increases.

B. Effect of change in bolt preload

When the bolt preload is increased from 50 kN to 173 kN, load at the critical slip of bolt was increased up to a maximum of 49.95 % at the fixed support and 62.97 % at the roller support. The ultimate shear strength is also increased when the preload of bolt is increased. The percentage increase of ultimate shear strength at the fixed end support was 31.31% and 25.51% at the roller support. The energy absorption of bolted connection was increased up to 3.591 % at the fixed support and 7.120 % at the roller support. The energy absorption capacity of bolt did not show much variation when the bolt preload was increased. The load at critical slip of bolt was increased predominantly on increase of applied bolt preload. The main factor which affects the load required for making the critical slip of bolted connection is the applied preload force to the bolt.

C. Effect of change in tensile strength of bolt

When the tensile strength of bolt is increased from 830 Mpa to 1220 Mpa the load at critical slip of bolt not shows variation. The stable nature of load for the critical slip of bolt is due to the constant application of preload to the bolt. The percentage increase of ultimate shear strength of bolt was maximum up to 19.17 % at the fixed support and 20.38 % at the roller support. The main reason for increase in the ultimate shear strength of the bolted connection is the increased tensile strength of the bolt. The energy absorption of bolted connection was increased up to 134.21 % at the

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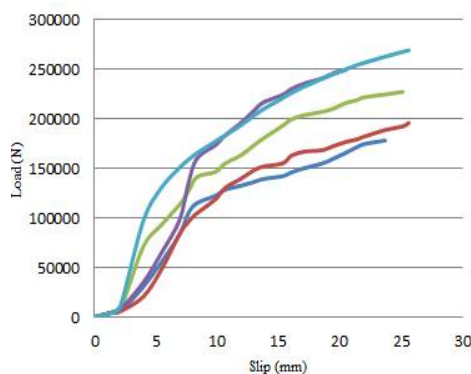
fixed support and 123.73 % at the roller support. The tensile strength of the bolt has a predominant effect on the energy absorption of the bolted connection.

D. Effect of change in hole clearance

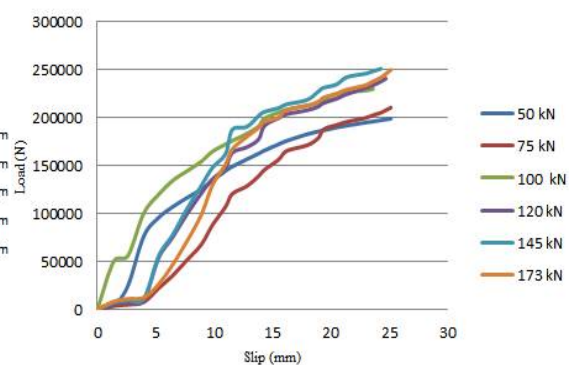
As expected, the clearance between the prefabricated hole and the bolt directly affects the value of the first critical slip. Here the critical slip of bolt was changed according to the provided hole clearance. The specimens with a significantly larger clearance hole, had not only a larger first critical slip, but it also required a smaller force to cause first slip, compared with specimens with the normal sized holes. The When the hole clearance of bolt was increased ultimate shear strength of the bolt at the fixed support was decreased up to a maximum of 61.02 %. Similarly, for the bolt at the roller support, the maximum decrease was up to 59.58 %. The ultimate shear resistance of the bolt has not much change when clearance is changed from 0 to 4 mm. The ultimate shear resistance of the bolt is reduced drastically when the hole clearance is more than 4mm. When the hole clearance of bolt was increased the energy absorption of bolt at the fixed support was decreased up to a maximum of 75.86%. At the roller support, the maximum decrease in energy absorption of bolt was up to 75.27%. When the hole clearance was beyond 4 mm, the energy absorption of bolt decreased drastically.

E. Effect of change in pitch of bolt

When the number of bolted connection was increased from 2 to 4 the load required for critical slip, ultimate shear strength of bolt and the energy absorption capacity of the bolt were doubled. 75 mm pitch bolt gave maximum load at critical slip, ultimate shear strength and the energy absorption of bolt. Increase in pitch of bolt from 125 mm to 150 mm decreases the ultimate shear strength, load required for the critical slip of bolt and the energy absorption capacity. From the analyses it is obtained that 75 mm is the optimum pitch for 22 mm diameter bolted connection. Fig 2 shows the the effect of varying parameters such as diameter and tensile strength of bolt, preload and hole clearance and pitch of the bolt on the load-slip relation up to the ultimate load and corresponding ultimate slip. The load-slip behaviour shows the ultimate shear strength and corresponding ultimate slip of bolt. Fig 3(a) shows example figure of total deformation of the specimen with varying diameter of bolted connection obtained after the FE analysis in ANSYS work bench 16.1. It gives total deformation of the specimen. Fig 3(b) shows the example figure of deformation of bolted connection with respect to varying bolt diameter obtained from the ANSYS analysis. It gives the ultimate slip of bolted connection beyond which it was failed.



(a)



(b)

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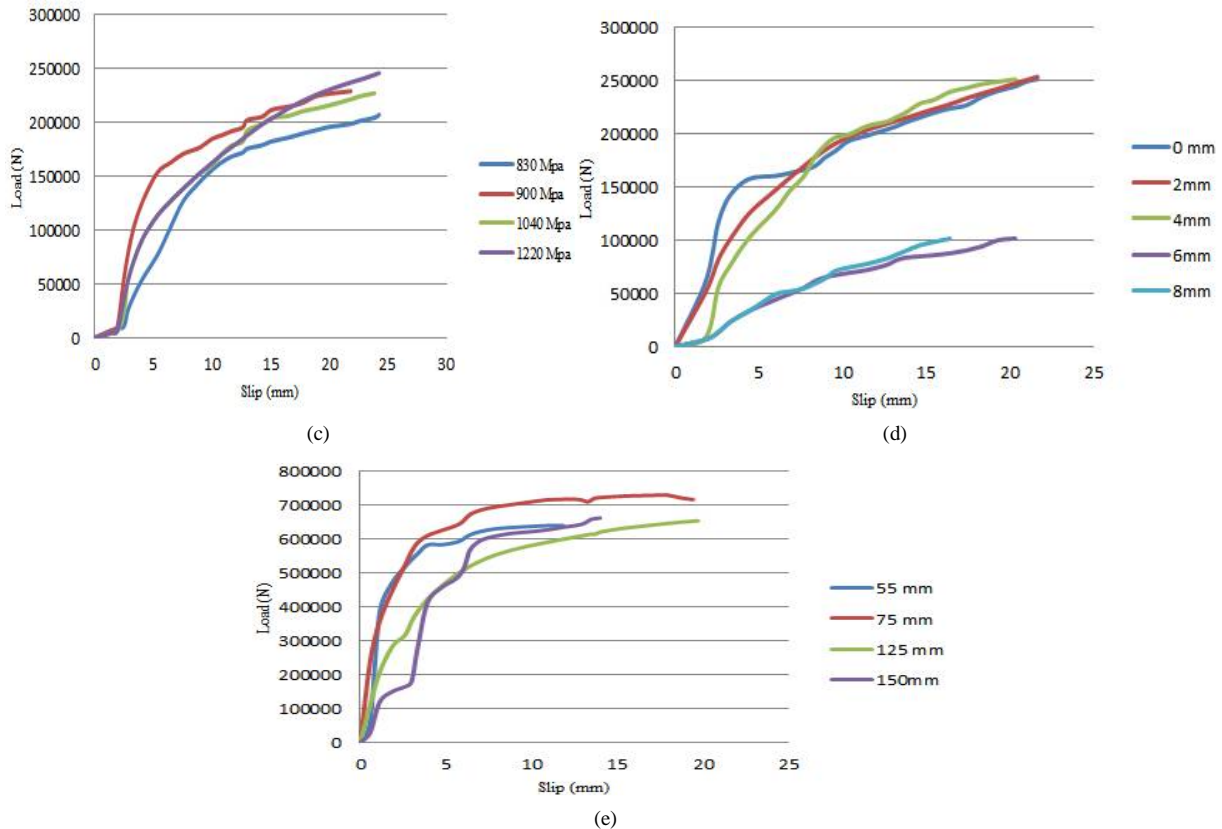


Fig. 2. Load-slip response of bolted connection with varying parameters (a) varying bolt diameter (b) Varying pretension (c) Varying tensile strength of bolt (d) varying hole clearance of bolt (e) varying pitch of bolt

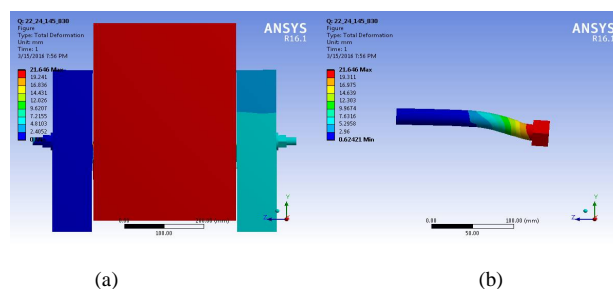


Fig. 3. Deformation figure from ANSYS analysis (a) Deformation of specimen (b) Deformation of bolted connection

IV. CONCLUSION

A set of total 26 number of finite element models of push-out tests has been developed to investigate the behaviour of bolted shear connectors in composite beams using ANSYS software. The ultimate strength and the load-slip behaviour for the shear connections were examined. Extensive parametric studies of push-out specimens with different bolt pretensions, clearances between the holes and the bolts, diameters and tensile strengths of the bolt connectors and pitch of bolt were performed by using the numerical model. The results showed that the diameter, tensile strength of the bolt connectors and bolt pretension had very significant effects on the ultimate shear resistances of the HSFGB shear connectors.

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When the hole clearance is increased beyond 4 mm the ultimate shear strength is decreased drastically. The increase of bolted connection from 2 to 4 numbers doubled the ultimate shear strength of bolt. 75 mm is found as optimum pitch for 22 mm diameter bolted connections.

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