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GROUTED SLEEVE CONNECTION FOR PRECAST CONCRETE MEMBERS

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ABSTRACT

Precast concrete structures have gained preference in the modern construction industry because of the multiple advantages they offer. The connection of precast members is an important aspect to consider in the design of structures with precast components. Grouted Sleeve connection, one of the famous connector types, is made of the trio of reinforced bars, high strength grouting materials and a ductile iron cylinder. This article compares the finding of recent experimental research findings on grouted sleeve connection and establishes the relationship between the three components of the connector to enhance the performance of the splicing agent. It is found that the tensile performance of the connector increases with the embedded length of the bar for a normal sleeve. An effective embedded length set between 6 and 8 times the diameter of the bar will maximize the tensile performance of the connector. The increase in diameter of the sleeve cylinder, the compressive strength of the grout and the length of the bar embedded and its surface will affect the bond performance and the mode of failure under tensile load. `

KEYWORDS

Precast concrete, Sleeve connector, Bond strength, Embedded length

INTRODUCTION

Precast Concrete (PC) is a currently promoted technology in concrete structures. It is believed that PC technology has been used in ancient Rome for tunneling. The current PC technology commonly used was first used by Alexander Brodie, a British engineer in 1905. In the USA the technology was used in the construction of a Bridge in Pennsylvania after the World War II [1, 2]. The most developed countries have embraced the technology with Japan and China also being among the beneficiaries of the invented technology. The concrete members are prefabricated far from or near the site and have relatively gained preference over cast-in-situ concrete most especially for high raised buildings, multi-storied car parking, highway bridge supports among others [3, 4].

There are many listed benefits of using PC over the cast on-site concrete. Some of the benefits include the reduction in construction’s required time, avoidance of unnecessary delays caused by extreme weather conditions, decreased environmental pollution, enhances architectural ventures which could not be possible with the traditional technology, a limited number of laborers on site. In addition, the new technology decreases the risks of site-related accidents and labor cost and offers the ability to produce very good quality concrete with high strength in the controlled environment [5, 6].

Due to the ability to produce very high strength concrete in a controlled environment, structural engineers picked interest to maximize the use of precast elements for structures which are expected to support the heavy load. It is now a matter of knowing how to connect the different PC structural members safely together [6].

CONNECTIONS FOR PRECAST CONCRETE

Briefing on precast connection

A connection in reference to precast concrete structure means a construction between two or several precast concrete components. It can, therefore, comprise multiple joints [7].

Connections are critical structural elements in precast concrete construction. Beside influencing the type of frame to use and the erection process they are responsible for proper transmission of the loads between structural elements and ensure the robustness of the structure in the overall continuity. It is evident that the main difference between precast and traditional cast on-site concrete lies on the continuity of the structure at the nature of the connection between different members [8]. The traditional cast on-site concrete has the continuity of the structure at the connection as the result of the site set up of the reinforcement bars encored together in the foam work before casting and vibration of fresh concrete. For the PC structure gets its continuity from a good link between two or more structural members being erected on site.

Precast concrete members are linked to each other by a mean of connections. There is ongoing research on the various types of connections to confirm the reliability of the performance of these connections to ensure the integrity and safety of the structure. It is crucial to understand that a lot of reactions that are responsible for structural stability happen at a junction between two different structural members.

Design consideration and criteria of PC connections

The main role of a connection for both precast structures and cast in situ structures is to provide adequacy in structural loads transferring without undergoing any considerable deformation [9]. For precast structures, a connection ensures members are safely linked, provides the support during the erection of other members, and accounts for the integrity of the final structure's performance. In the whole process, the structural engineer ensures the connections serve for the continuity of the structure as a whole. Any bridging gap at the joint in the connection will compromise the structural integrity to an extent [4].

While ensuring the structural integrity at the connection, it is also important to acknowledge that the conception of the connection should always be simple in order to facilitate the erection process and enable final loads transmission [5]. The designer should consider the connection's design criterion, the ease of mounting members on-site, the strength, the durability, the fire resistance and the most importantly the material which is preferably ductile with high strength in most cases [1, 5]. There is a diversity of connections that link precast concrete elements together.

After manufacturing the different components of the precast concrete structures, engineers have a task to mount the different parts together while ensuring structural integrity. Currently, there are many ways of connecting the precast components together in order to form a performing structure. Advancement in research on connections discovered the feasibility of a hybrid structure which is the combination of steel structure and PC reinforced structure to provide safe links between members. In this document, we will focus on one of the common types of connection used in the precast structure.

Characterization of connections

The connections between the precast elements are either wet or dry. Wet connections rely on the splice of the reinforcement bars. They're usually achieved by a reinforcement lapping setting and an onsite concrete fill in the lapping dowel [10, 11]. Though wet joints involve extra cost and time they enhance good ductility of the connection and do not hamper important movement in the connection [12]. In 2019 Scholars in Japan rate the performance of the wet as better or similar to the monolithic cast-in-situ intersection [13]. The dry connections are set up by means of the steel materials and are in most cases used for fixed connections [10, 12]. Dry connections can be achieved in practical by bolting, anchoring or welding on site. In times of overstress, they have a brittle failure [11, 12] and hidden cracks can develop bellow the anchorage without being noticed [14]. Much as [15] reports a good performance of the joints, wet connections are more preferable than the dry connections. In other cases, the connections in precast structures are classified differently. Based on the elements they connect we have shear wall connections, slab connections, walls connections, beam to column connections, beam to beam connections, column to columns connections, column to foundation columns [8, 11]. Other scholars have classified the precast connections according to the major force actions which they convey. We, therefore, have shear connections, tensile connection and compression connection [7]. Much as there may be the presence of torsion action in the working of connection, its influence is relatively minimal and not an object of focus considered in concrete structures unless for special cases. It is important to therefore notice that connections are designed in consideration of the members that are to be connected.

Thus, a satisfactory connection between precast components can be achieved in several ways which in most cases include bolting and threading, mechanical connectors, anchors, bar couplers, special insert, shims, welding, grouting and etc. In the diversity of connections settings, the structural engineer should remain innovative in adapting the chosen connection set up to his site and have sufficient information about the working of that connection in particular [8].

GROUTED SLEEVE SPLICE (GSS)

Grouted splice is one of the preferred precast mechanisms to link two different members. Alfred A. Yee invented it in 1960, GSS is a hollow cylinder made with ductile materials of iron, where two reinforcement steel bars are connected together [16-19].

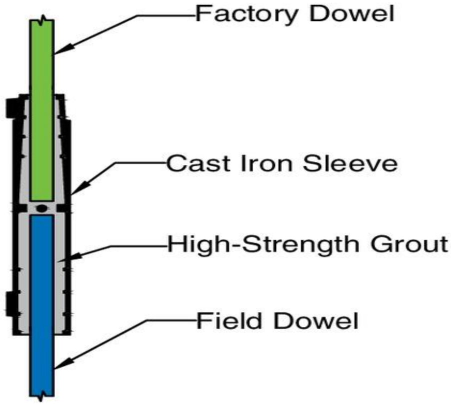

Fig.1- Elements of the GSS connector

In Figure 1, the image also used in [20] provides a pictorial understanding of the connection set up of grout sleeve itself on the left and the description and details of the components of a full grouted sleeve with the trio component of sleeve, bar and grout.

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To achieve a proper bonding capacity of the rebars, high strength grouting materials are inserted in the sleeve. Grouted sleeve connection is used in precast concrete to connect a column to column, beam to column connection, column to foundation connection as well as shear walls connections.

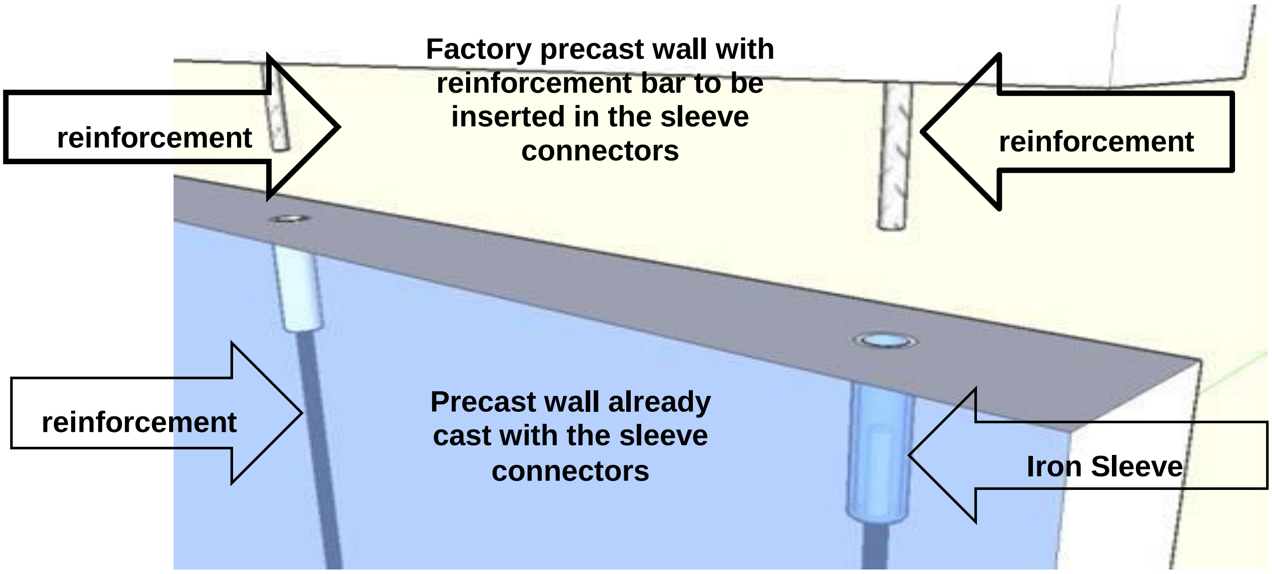

Fig.2 - Erection of Precast members using grouted sleeve connector

The edited image extracted from [21] captures two wall panels yet to be connected together by a grouted GSS, an illustration of the in-situ erection setting.

A grouted sleeve connection used for precast members splicing comprises of a cylindrical ductile iron duct sometimes made of steel, the reinforcements bars and the grout. It is important to understand that the composite materials of each one of the trio components of the sleeve matters for a good performance of the connector [22]. The sleeve enhances the grout confinement around the steel reinforcements [6]. It serves as a connecting agent between the field's reinforcement and the factory member's reinforcements during the erection process, keeps reinforcements in proper alignment and holds the connection components together while allowing the inflow of grouting material in the sleeve through the two holes [23]. As illustrated in Figure 2, the two reinforcement that participates in the connection of the walls have their lapping inside the connector. The reinforcements and inserted grout enhance, therefore, the continuity of the structure at the connection inside the GSS connector [16]. The grout is a high strength concrete material that fills the void space between the bars and the inner surface of the sleeve connector. The grout confinement in the sleeve serves as a bond between the two reinforcement bars being connected [16, 24].

Factors influencing the performance of the sleeve

The performance of the GSS connector under loading highly depends on the strength of the grouting materials and their confinement inside the connector [25-27]. The appropriate grout material is preferably a high compressive strength material which has non shrink property [28]. Insufficient grouting and the presence of grouting defects in the steel sleeve will decrease the load load-bearing capacity at the connection and will lead to the premature failure of the set up [28, 29]. Defects in grouting materials will also damage the adhesion between the grout and sleeve inner walls and bar surface which is paramount in the connection proper performance. A 30 percent ratio of the defect in grout for a sleeve will lead to premature failure of the connector [19, 29]. There is a strong agreement between the deliverables and findings of the existing experimental research by deferent authors on the impact of the grouting defects in relation to the confinement of the grout in the sleeve and the performance of the connector. But the gap between the research specimen set up with artificial defects and the suspected existing defects in the connection set up is relatively big. Up to now, the research on grouting defects within the connector does not reflect the real case. Detection of small defects in the sleeve by means of nondestructive tests was proved inefficient and not accurate in defects sizing within the sleeve[30, 31]. The research conducted by [29] used soil and foam as the defects while [28] without specifying the nature of defects in his experiment, he affirms to have defects in the vertical plane of the sleeve along the path of the upper embedded length. His defects are in different sizes. We can make an observation that both of the experimental work later experimental works do not reflect the ideal scenario faced on site. There is a need to pursue the in-depth study on grouting materials ,their propagation in the sleeve and the way they perform with the connector's other components [32].

The bond strength between the bar and the grout also depends on the bar structure, the grout's compressive strength, its chemical adhesion and the diameter of the steel sleeve, The bar's roughness and the bearing of the steel bar [33]. Most experimental work use 28 days normal aged grout of strength varying between 58 Kpa in [34] up to more than 80 Kpa in [28]. The highest compressive strength grout is the most preferred in the field and hence much more used for many experimental works and field works. The findings after the experiment conducted in [25] establish that the strength of the bond between the reinforcement bars and the steel sleeve increases proportionally with the compressive strength of the grout. Hence the compressive strength of the grout will increase the bond performance of the connector. The mechanism of load transfer by grouted sleeve connector depends on the bond between all the components involved which is provided by the grouting materials [18].

$$u = \frac{P}{\pi d_b l_e} \tag{1}$$

The Equation (1) also used in [25, 34, 35] can find the average bond stress when the connector is subjected to a load. P is the force in the bar, πd_b is the nominal perimeter of the bar and l_e is the embedded length of the bar.

The data from the experimental study [36], were used to plot the graph in Figure 3. A selection of data with different bars diameter respectively 16,18 and 20 were picked under different embedded length with other parameters constant to study the grout bond response.

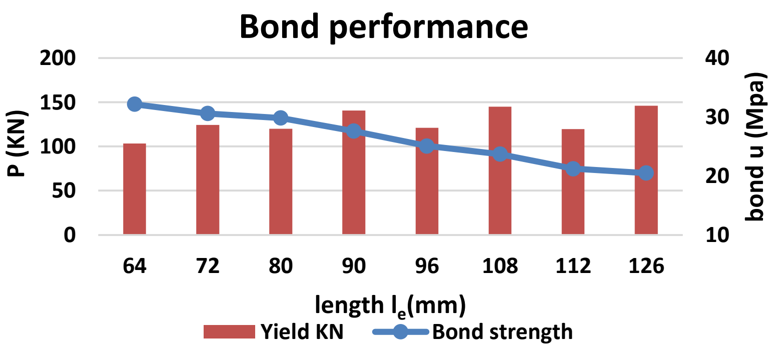

Fig. 2- Behaviour of bond strength under increasing embedded length

The bond strength u is indirectly proportional with the embedded length l_e. It can be observed from the graph that the difference in the bar diameter has no impact on the sloping line of the bond strength under the increasing embedded length of the reinforcements. The tensile capacity of the connector is not linked to the bond strength only but varies according to both the

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bond and the embedded length. It is a result of a good set up of all the features in the sleeve [25]. Regardless of the bar diameter in the sleeve and increase in l_e will weaken the bond. The deduction from the above graph is that the bond strength of the grout within the connector will decrease with the embedded length of the bar. The bonding mechanism within the connector is enhanced by the confinement of grout within the connector therefore, an increase in embedded length will decrease the confinement of grout within the connector and hence compromising the bonding strength [16].

There is an existing link also between the surface' nature of reinforcement bar and the connection performance. The need to find the anchorage of the bars have lead researchers to investigate the type of bond existing between the grout and the reinforcements [34, 37]. It was found that bars with a smooth surface have a weak bond with the grout. In an experiment conducted by [35], a specimen with the reinforcement with rough circumference had a good grout bond capacity and failed by bar fracture while the smooth bar failed by bar pull out of the sleeve. The interdependence of bond adhesion of the grout and the bar in relation with the bar's roughness is mentioned as well in [33]. This behavior is justified by the additional frictional resistance that the ribs on the rough surface of the bar make with the grout. Other researchers managed to get an expression that links the embedded length of the bar to the performance of the sleeve under loading conditions [18].

The alignment of the two bars being connected within the sleeve is crucial for a good performance of the connector. Misalignment of the reinforcement in the sleeve bar will compromise the distribution of the tensile stress within the connector [6, 21, 25]. The impact of the alignment on the performance of the connector is emphasized in [3, 6]. The same issue may aggravate deformations in the connector and weakens the surrounding grouts in times of load application. The same can precipitate the failure of the connection [37].

The diameter of the bar increases linearly with the tensile capacity of the connector [24, 32]. It is logic to establish a linear relationship between the tensile performance of the GSS connector and the diameter of the reinforced bar if the set-up of components of the connector are all carefully integrated since the same relationship exists between the diameter and the tensile performance of the reinforcement bar.

To determine the total embedded length of the bar the following expression can be used:

$$l_e = \frac{P}{\pi d_b u} \qquad (2)$$

l_e is the embedded length, P is the applied force, d_b is the bar diameter, and u is the bond strength between the bar and surrounding grout [3, 26].

In his experimental work [24] established the relationship between the length and the tensile behavior of the grouted sleeve connector.

From their experimental findings in [26, 34] it can be established that the expression $l_e = 16d_b$ where l_e is the length of the sleeve and d_b the diameter of the bar can be used without any weakening of the sleeve performance. Further investigations on the right length being eight and twelve times the diameter of the bar were also proven safe to use [34]. The safe embedded depth of the bar should be selected in consideration of the type of the sleeve being used. Headed couplers require a shorter embedded length than the normal sleeve.[34]. [35],[25] and [21]on the other side after their experiment realized that the expressions $l_e = 6d_b$ and $l_e = 7d_b$ will give the sleeve the tensile strength performance exceeding the requirement in ACI 318. The same expression was approved by scholars in China and the United Kingdom in 2019 after their experimental work on grouted sleeve splice with wedges [6]. There is a complete disagreement of research on the proper embedded length to use inside the steel connector. It is valuable to understand that, though the length of the bar has a linear relationship with the tensile performance of the connector, the embedded length is not the only parameter on which the tensile depends on. In [34] it is also agreed that the nature of the grout-bar bond, sleeve-grout bond and the compressive strength of the grout will have an influence on the tensile performance of the connector. Different setting of the connector will require different embedded length of the bar but the normal sleeve largely used will perform well at the embedded length between 6 and 8 times the bar diameter.

The data from [38] after the experiment were used to produce the following chart below showing the relationship between the embedded length of a 16mm diameter, the bond strength and tensile strength capacity.

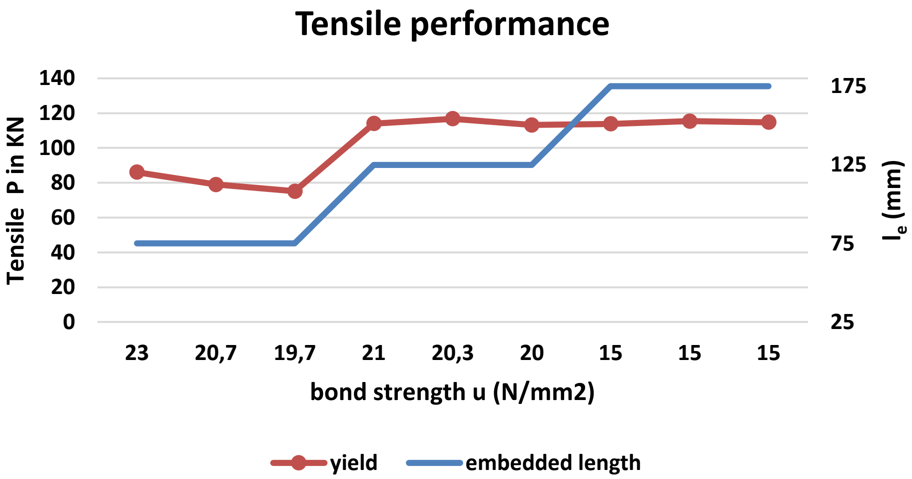

Fig. 3- Tensile performance for different embedded lengths

In Figure 4, decreasing bond strength at the same embedded length of the bar will decrease the tensile capacity. The increase of the anchorage length to the effective one will slightly decrease the bond capacity but significantly increase to the maximum the tensile capacity of the connector. Any additional length beyond the required embedded length of the bar will only decrease the bond capacity u without any effect on the tensile load-bearing capacity P.

The steel or iron sleeve should be able to ensure very good quality of bond strength [18, 32]. The structural and economical influence of the type of connector cannot be negligible. Different connectors influence both the embedded length and the grout bond strength depending on whether the sleeve is threaded or not, headed, wedged and etc. [21, 34]. The performance of the bonding grout with the sleeve depends on the nature of the inner surface of the steel or iron sleeve. Ribbed surfaces provide better bonding than smooth surfaces just like for the surface properties of the bar [24, 35]. Better bond performance of ribbed or threaded sleeve inner surface was reported by [26] in his conclusion. Sleeves with a threaded inner surface can increase the tensile performance of the connector. It was found in [38] that the tensile capacity of the threaded sleeves outperforms the performance of the normal sleeve with a smooth inner surface by about 36KN. The threads and ribs will enhance proper adhesion and improve the sleeve-bond strength hence creating a frictional resistance during the tensile test.

The ratio of the sleeve diameter to the bar diameter d_s / d_b counts also for the grout confinement effect of the sleeve and should lie between 2.66 and 3.55 [34]. The ideal ratios for specific bars were tabulated in the same document after experiment [34]. It is more preferable to have a tolerance of about 2.5 cm around the bars within the sleeve [3, 34]. An experimental study found that selecting a lower size of the sleeve diameter will improve the confinement in the sleeve enhance a better performance of the connector [37, 38].

Selecting the data from [6] in his experiment conducted in 2019, the chart below was plotted to mark the relationship between the bond strength, the sleeve diameter and the tensile performance of the sleeve.

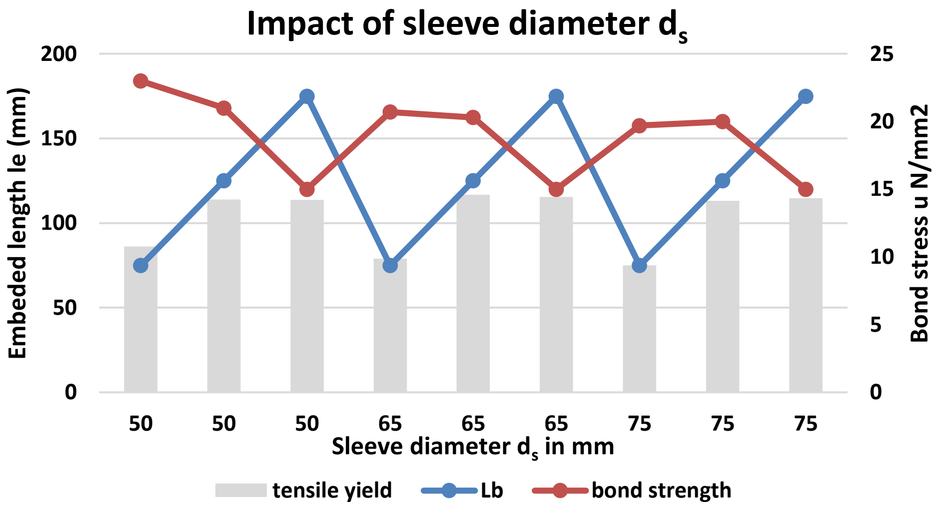

Fig.4- The impact of the diameter of the sleeve cylinder

At the same sleeve diameter and increase in l_e will decrease the bond. Likewise, at the same embedded length, and increase in the sleeve diameter will decrease the bond strength. The tensile capacity increases with the length up to the safe embedded length. Any additional length is unnecessary. A larger sleeve diameter will weaken the bond and cause a slight regress in the tensile capacity.

The data in the experimental work tabulated in [38] were selected to illustrate the relationship between the diameter of the sleeve and the bond at a different embedded length of the bar. (d_b=18mm)

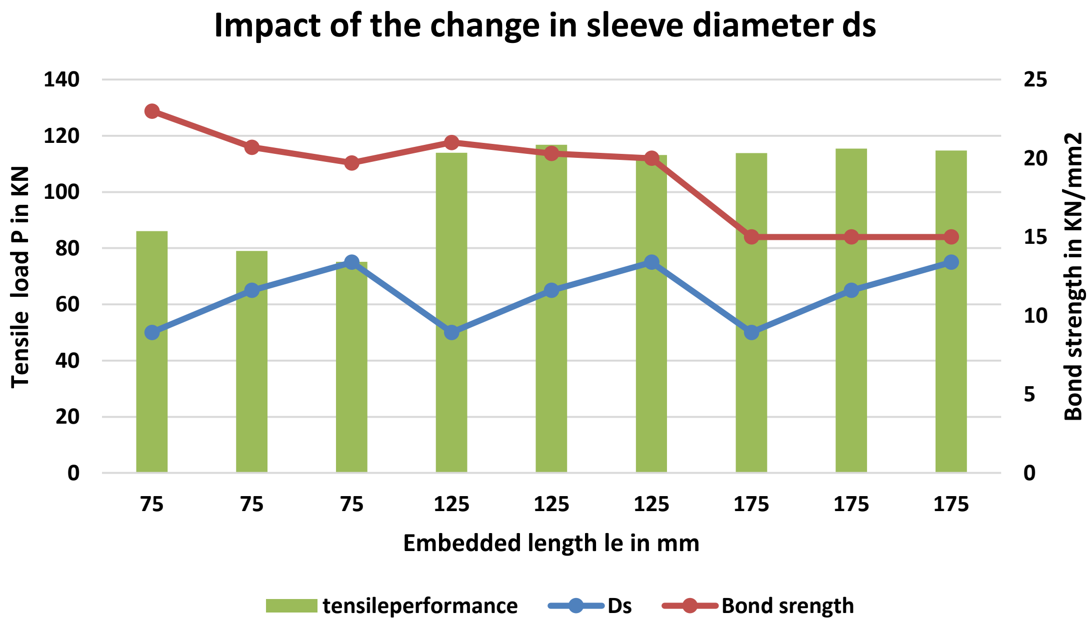

Fig. 5 - Impact of sleeve diameter

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From the above chart, an increase in the sleeve diameter will result in a decrease of the bond strength under the same embedded length of the bar or even a shorter embedded length. The tensile performance increases significantly with the embedded length up to the required embedded length for this case 125mm which is about $6.9d_b$. Despite the decrease in sleeve diameter, an increase in embedded length still reduces the bond strength. An increase in sleeve diameter and in embedded length will both decrease the bond strength until the minimum bond strength where no further weakening of the bond is observed. The tensile capacity is maximum at the embedded length 125mm. No further improvement in performance both on the bon and tensile is not possible.

Mechanical interlocks play a key role in case of bond failure the performance of the connector relies on frictional resistance and mechanical interlocks [39].

Performance of the grouted sleeve connection

It is reported that the PC had poor performance in seismic regions and was therefore previously used consciously in seismic regions with a lot of precautions and relatively high risks [11]. The grouted sleeve connection was found through much experimental work to withstand several earthquakes without undergoing any major deformation [35]. The wet connections are more preferred more than the wet in seismic zones because of their ability to allow movements within the connection setting [10]. No wonder, the PC structures now exist in seismic zones of Japan, China, Canada and etc. The nature of the connection allows to the connection very high ductility there hence there is displacement inside the connection due to apply load before the ultimate load that causes the connection to fail. The load displacement curve of the grouted sleeve connector is homogeneous and the connection does not register a brutal failure before yield [24]. This accounts for the good ductility of the connector previously mentioned. An experiment conducted by[17] on columns with grouted sleeve splice confirmed that grouted sleeve connection is safe to withstand earthquakes. The homogeneity and the non-brutal failure of the sleeve in the load displacement curve of a grouted sleeve connection is an indicator of good confinement and proper bonding between the two reinforcement being connected [24]. The good tensile performance of the grouted sleeve connection is proven by the bar fracture outside the sleeve during the tensile test experiments [16, 38].

In his experimental research, [39] found out that grouted sleeve connections allow axial movement and have very good energy dissipation without undergoing considerable deformation. The same author highlights poor response to critical rises in temperatures. The poor thermal conductivity within the connected components is also confirmed in [40].

The poor performance of the connection when subjected to high temperature is the disadvantage of the connection [41]. Though proper link can be achieved by the GSS, in case of a fire outbreak, the connection will be weakened. At temperatures above 500^0F, the steel materials in the structure will start losing their strength properties [42]. Concrete cover on top of the sleeve connector made also out of steel should be enough in order to provide adequate protection of the connection. Isolation of the connection and its protections should be a priority while setting up the connection. Investigations should also be carried out and confirm the fire endurance of the connection the point at which the weakening of the GSS connector will compromise the load-bearing capacity of the connector. The later compromise may cause the collapse of the structure.

Improvements of the sleeve

Some engineers use a spirally confined lap which is a new technology proposed and being assessed to improve the confinement in the connector for the precast members intended to carry heavy structural loads [18]. This improvement meanwhile is achieved outside the connector but is meant to enhance the compressive performance of the connection.

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Further ongoing improvements of grouted sleeve connection range from half grouted sleeve with mechanical interlocks where one part of the sleeve is grouted and another end is fixed. In Beijing, there has been the creation of a grouted sleeve with threaded and multiple shear keys [6, 43]. Threaded sleeves have been observed to have a considerable improvement in tensile performance. The new technology of incorporating a shear key in the connector is reported to improve the grout-pipe bond failure by preventing it with a minimum of three shear keys [21]. A modification of the sleeve with wedges and other tapered head have been used to conduct an experiment that found an improvement in the performance of the modified sleeve.

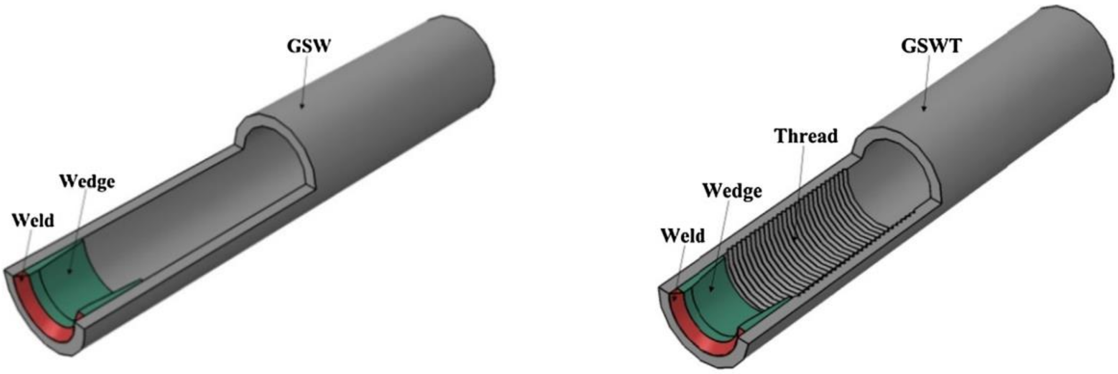

Fig.6- Sleeve cylinder with wedge and with wedge and threads

All improvement and customized sleeve should, therefore, be subjected to experimental tests of their ability to convey structural loads before they can be used. Other researches on the improvement and customized sleeve connector remain confidential and private.

CONCLUSIONS

Many experiments conducted on grouted sleeve splice approved the working and the performance of the connector under loading conditions. A good combination and a proper set up of the trio components in the right geometry and specified properties will enhance a safe connection. The GSS has three major modes of failures that are reported in the experimental works reviewed: bar bond failure also referred to as bar pullout, bar fracture outside the sleeve, and grout- sleeve bond failure [16, 32, 44].

The bar pullout case has been common in the specimen with weakened bond strength as a result of poor adhesion between grout and rebars. Much as there is gap in studying the distribution of the grouting materials inside the sleeve, it can be realized that the additional length of the bar anchored in the sleeve beyond the effect which is placed between 6 and 7 times the diameter of the bar will weaken the bond without additional tensile capacity [6, 18, 26]. Excessive length beyond the required will be the cause of bar pulling out of the sleeve.

Bar fracture is the best mode of failure for a sleeve connector. This failure means that the connector setting outperforms the tensile capacity of the bar. The connector's tensile performance is 1.25 times the tensile performance of the bar inserted. This means the connection achieves the tensile requirement of the connector. The impact of the tensile yield capacity of the reinforced bar is not assessed by many scholars yet believed to have a considerable impact by [45, 46].

A safe length of the embedded portion of the bar with rough surface inside a steel sleeve with a small sleeve diameter d_s and the ribbed inner surface will make a better set up for a good performance of the splicing agent.

Grout to sleeve bond failure is the least common type of failure. It is the type of failure resulting from a poor bonding between the sleeve and the grout. Usually common with sleeve without proper interlocking mechanisms and smooth surfaces [21, 26]. A small diameter sleeve will enhance good bonding than a wider diameter of the sleeve [45].

Research derivable reported the good performance of the connection in earthquakes and good capacity of energy absorption. Under fire outbreaks, the connection is weak due to poor thermal conductivity.

FURTHER RESEARCH

We recommend that the distribution of grouting materials in the sleeve and their impacts on the connector's performance should be clearly understood. The impact of their various confinement in the sleeve should resort in order to improve the safety of the connection.

We advise conducting a study that should focus on increasing the bond together with the length of the bar then assess the tensile capacity of the connector. Otherwise, provide clear concepts and equations that explain the existing trend of inverse proportionality between the bond and the embedded length of the bar.

Scholars should link the tensile yield of the reinforcing bar to the overall performance of the sleeve connector with an emphasis on the tensile contribution of the bar [46].

Many studies were done on GSS connection focus on bond strength, which is key, but a study on the contribution sleeve material on the tensile performance would be more insightful.

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