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Structural Performance of Shear Connectors

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ABSTRACT

The top flange of steel composite bridge girders are furnished with a shear connector, which is a steel projection that facilitates the necessary shear transfer between the steel girder and concrete slab to permit composite action. Shear connectors are essential for building solid connection points that withstand shear loading. The shear connectors are placed at the interface between steel beam and concrete slab, and they are responsible for transferring the horizontal shear forces that are formed due to flexural action. The steel concrete composite structures can be characterized as integration of two different elements which deform as a single entity under loading conditions. The advantage of these types of structures is the combination of material advantages making them structurally economical, efficient and sustainable. Shear connectors are the fundamental components of composite structures since it acts as an intermediate between the two entities and ensuring that the whole component acts as a single structural entity under loading conditions. With non-composite girders, the concrete slab and steel girders function independently in flexure. Hence, the load-carrying capacity of the girders might be raised by more than 50% compared to that of non-composite girders by employing shear connectors to connect the two structural components. This seminar also deals with importance of shear connectors in structural performance, types, applications, tests, design and performance of shear connectors.

***Keywords:-** structures, composite, Shear connectors, steel, construction*

1 INTRODUCTION

On the top flange of steel composite bridge girders, there is a steel projection known as a shear connection. Shear connectors' primary function in composite beams is to transfer longitudinal shear stresses at the point where the steel beam and concrete slab meet, resulting in the behaviour of the composite beam. Shear connectors are a critical way of creating strong connection points that hold up to shear loading. The headed stud, also known as a shear stud, is the shear connector that is most frequently used. Block and hoop and channel connections are additional shear connector types that are frequently utilised as an alternative to tightly spaced shear studs when substantial shear transfers are required. To withstand shear at the appropriate points, shear connectors or studs are spaced apart. As a result, the spacing of studs varies from the support to the mid-span depending on the needs and cost. Shear connectors on the top flanges of the steel girders give the slab and the girders a way to work together in a composite motion that increases stiffness and strength. In composite ,, shear connectors between concrete slabs and steel beams can be crucial to a structure's seismic response. They can be employed to distribute the significant horizontal inertial forces in the slab to the primary lateral load resisting parts of the structure and provide the crucial shear link for composite action in flexure. Such shear connectors experience reverse cyclic loading during an earthquake. This part ensures the shear transfer between the steel profile and the concrete deck, which permits the development of a composite action. In order to strengthen these floor systems, it may be cost-effective to connect the existing concrete slab and steel girders. This allows for the development of composite action. With non-composite girders, the concrete slab and steel girders function independently in flexure. Hence, the load-carrying capacity of the girders might be raised by more than 50% compared to that of non-composite girders by employing shear connectors to connect the two structural components. Shear connections are welded to the top of the steel girder before the concrete slab is formed in order to provide composite action when building new bridges. An important consideration in the construction of composite beams is the shear connectors. Shear connections come in a variety of forms, and they are frequently characterised as stiff or flexible according on how the shear pressures are distributed and how well strength and deformation work together.

NEED FOR SHEAR CONNECTION

The need for composite action naturally results in the shear flow or shear stress between the steel girder and concrete slab. Because to the low value of the secondary moment of inertia, the beam and concrete slab would operate separately in the absence of a shear connection and have a limited capacity to support loads. We can create a significantly stiffer and stronger segment by using shear connectors to join the two halves together and stop slip between them. To illustrate the distinction between a composite and non-composite beam, a straightforward example is provided. A simple support beam is created as composite and non-composite sections, as shown in Figure 1. The secondary moment of inertia of the composite section for the portion depicted in Figure 2 is four times that of the non-composite section, indicating that the composite section is four times as stiff. The illustration unequivocally demonstrates that the performance of the composite section depends on the connection at the interface between the steel girder and concrete deck.

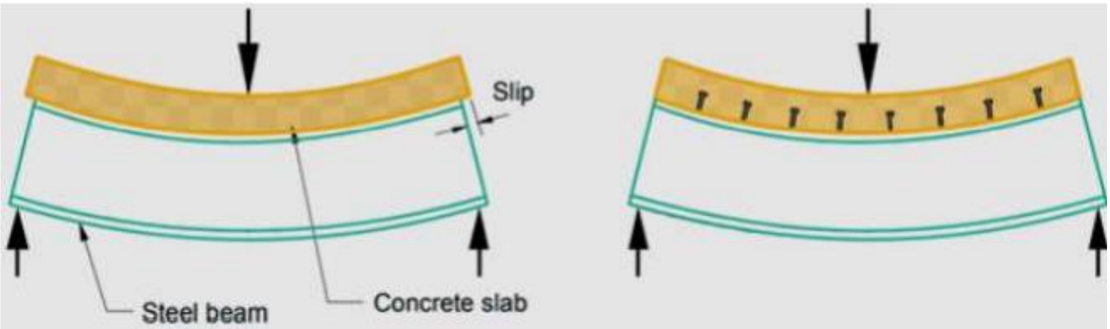

***Fig.1:**-Bending behaviour of Non-Composite and Composite beam*

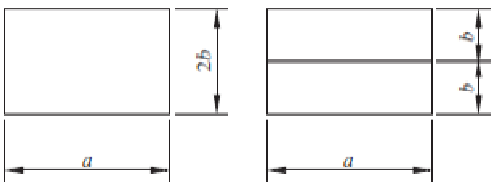

***Fig.2:**-Cross section of Composite and Non-composite beam*

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STRUCTURAL BEHAVIOR OF STEEL-CONCRETE COMPOSITE BEAM USING BOLTED SHEAR CONNECTORS

A concrete slab supported by steel beams is a frequent feature of many structures, including bridges. The beam is known as a composite beam and is becoming more and more common in contemporary buildings if the steel beams are attached to the concrete slab using various types of shear connections so that the two act as one unit. This is as a result of their superior corrosion resistance and high strength-to-weight ratio when compared to conventional concrete or steel parts. Also, because to their easy construction, outstanding structural performance in terms of stiffness, and large economic benefits, they are a beneficial structural shape. Although composite beams can be made from a variety of materials, steel is most frequently utilised as the beam and concrete is used as the slab. Despite having extremely distinct properties, steel and concrete work well together because steel works well under tension while concrete works well as a slab. According to Figure 3, the concrete slab is largely susceptible to compressive stresses in this situation while the steel beam is primarily subject to tensile stresses, thus exploiting the positive characteristics of each material. Concrete can prevent this from happening because steel components are relatively weak and prone to buckling. In addition to providing corrosion protection, concrete also serves as thermal insulation in hot climates, whereas steel gives the structure flexibility. A member's positive moment capacity can increase by up to 120% over a bare steel beam thanks to composite action, according to a rigid-plastic analysis of a composite beam section. Moreover, the usual solid concrete slab resists lateral-torsional buckling at the top flange with a thickness of 75 mm to 100 mm.

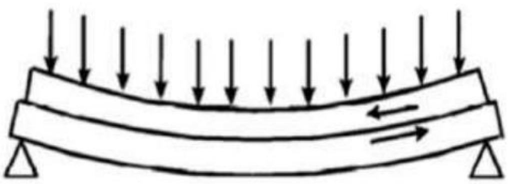

Fig.3:- *Non-composite beam*

Composite beams are more rigid and load-resistant when compared to non-composite beams, and when they are believed to be in an infinite condition, shear connectors, as shown in Figure 4, prevent any slip between two structural elements.[1]

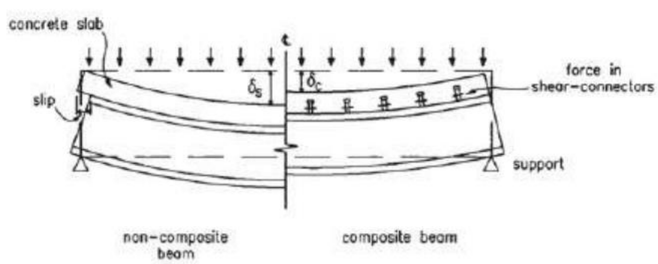

Fig.4:-*Comparison of composite beam v/s non-composite beam*

The transfer of longitudinal shear loads at the intersection of the steel beam and concrete slab, which determines how the composite beam behaves, is the primary function of shear connectors in composite beams. Composite beams use shear

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connectors in a number of different configurations, such as headed studs, perforated ribs, t-rib connectors, oscillating perforated strips, waveform strips, t-connectors, channel connectors, and non-welded connectors. Headed stud shear connectors are the most popular method for achieving the composite behaviour.

This is because the headed stud shear connections, which are installed in the cast-in-place concrete slab and welded to the top flange of the steel beam, may almost perfectly create the composite action. In such composite beams, the concrete slab and the steel beam are commonly connected by mechanical shear connectors, facilitating the essential shear transfer at the steel-concrete contact and assuring effective composite action. The headed stud shear connector, which provides a robust and ductile shear connection and is easy to install, is the most often used mechanical shear connector. Using headed stud connectors has the following further advantages:
They are useful for use in steel deck slabs due to their practicality, ease of arrangement of reinforcement through the slab, ease of production of large-scale sizes, and resistance to slab uplift provided by the standard dimensioned head.

4 REQUIREMENTS OF SHEAR CONNECTORS

• A shear connector's edge and a flange plate's edge must be separated by at least 25 mm.

•The maximum longitudinal distance is 800 mm or four times the thickness of the concrete slab, whichever is less, according to EN 1994-2, clause 6.6.5.5(3).

• The diameter of the shear stud shouldn't be greater than 1.5 times the thickness of the plate if the plate is being subjected to tensile stress or fatigue loading.
In other situations, the shear stud's diameter shouldn't be greater than 2.5 times the thickness of the plate.

•The height of the stud is determined by the underside of the shear stud head, which must extend at least 30 mm above the bottom transverse reinforcement.

5 CLASSIFICATION OF SHEAR CONNECTORS

There are four types of shear connectors utilized in steel-concrete composite structures: Adhesives, friction bonding, mechanical joints, and adhesion are all examples of adhesives, as shown in Table.5.1. Mechanical joints, which have a high composite effect even with a small contacting area, are the most common of these four types.[3-6]

Table 1:-*Classification of Shear Connectors*

Type	Method	Example
1	Mechanical joint	Headed stud, shape steel, block dowels, perforated-plate dowels and angle-connector
2	Friction bonding	High tensile bolt
3	Adhesion	Protruded rolled steels, such as checkered steel plate and rugged-surface H-shaped steel
4	Adhesives	Epoxy resin Headed Studs

Due to its ease of fabrication (welding), low cost, and consistent performance in all directions, headed stud connections have been utilised extensively in highway bridges. Shear connectors known as block dowels are frequently utilised in railway bridges. A semicircle of rebar is welded to a steel block or horseshoe-shaped plate to create this sort of connector. The concrete deck won't lift thanks to this rebar. In addition to headed studs and block dowels, perforated plate dowels and angle connectors are also used to join the concrete deck and flange plate in corrugated steel-web bridges. In Figure 5 typical shear connectors are seen.

Fig.5:-*Typical shear connectors*

For precast concrete deck panels, high-tension bolts are another connecting technique utilised in addition to mechanical shear connectors. It was recently discovered that the adhesion type connection approach, such as the usage of rubber-latex cement, was helpful in strengthening old bridge structures. According to reports, these materials are useful for improving the bonding at the steel-concrete contact. The long-term dependability and durability of such shear connectors are still an issue in the construction of new composite bridges, though, as the adhesion type connector maintains the connection only at the contact between the steel and concrete.

HEADED STUDS

The most popular shear connector is the headed stud, which resists both horizontal shear and vertical uplift stresses in composite steel-concrete constructions. As it is made to function as an arc welding electrode and simultaneously after the welding it functions as the resistant connector with an appropriate head, this form of connector helps with shear transfer and avoids lifting. This type of connector is widely utilised throughout the world as a result of the high level of automation in the workshop or on the job site.

Fig.6:-*Headed Stud shear connector*

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PERFOBOND RIBS

Many holes are welded into a steel plate that forms part of this connector. Dowels that offer resistance in both the vertical and horizontal directions are created by the flow of concrete through the rib openings. Its adoption has been encouraged since it not only secures the bond between the concrete and steel, but also makes it possible to better anchor the internal columns' hogging moment. To prevent concrete from cracking, it is standard to specify some reinforcing bars in the hogging moment region; however, the design of the connection typically does not account for the additional resistance that their presence provides. This connector seeks to transmit the reinforcing bar's forces from the region of hogging moments directly to the column flange. The additional components that are present in the internal and external connections are the seated and double web angles. The installation of the transverse bottom slab reinforcement, which is frequently exceedingly challenging, is the main drawback of this kind of shear connector. Due to the design of the ribs, these connectors are simple to install and offer strong shear and fatigue resistance capacities. The adoption of such connectors is determined by the fact that, in addition to ensuring the concrete-steel bond, it also provides a better anchorage of the interior columns' hogging moment reinforcing bars. It is possible to develop anchorage on such bars by putting the reinforcing bars via the perfobond web holes.

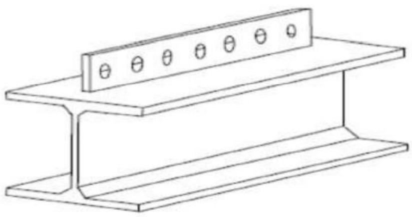

Fig.7:-*Perfobond ribs*

T-RIB CONNECTOR

The invention of this T-perfobond connector was driven by the requirement to combine the substantial strength of a block type connector with some ductility and uplift resistance resulting from the holes at the perfobond connector web. The T-rib connector detail reduces the influence of the prying action to prevent an early loss of stiffness in the connection. It could lower costs and require less welding effort because leftover rolled pieces can be used to make T-rib connectors. The T-rib connections are made in four steps, which are as follows

(i) initial profile (ii) web holes (iii) flange holes (iv) opposite flange

Fig.8:-*T-Rib Connector*

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OSCILLATING PERFOBOND STRIPS

This kind of connector has a greater load capacity than headed studs and T-rib connectors. Unfortunately, the performance of this connector in the case of ordinary strength and normal weight concrete is somewhat underwhelming because of the quick reduction in load capacity after the peak. The oscillating perfobond strips connectors work effectively because they don't exhibit this behaviour when used with high strength concrete, lightweight concrete, or concrete with fibres.

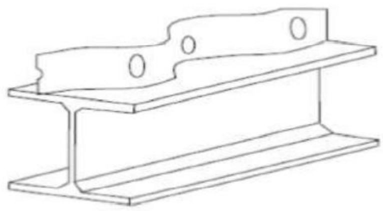

Fig.9:-*Oscillating Perfobond Strips*

WAVEFORM STRIPS

As contrast to a straight connector, the goal of the curved design is to improve the transfer of force between the steel and the surrounding concrete. Nonetheless, it is acknowledged that employing traditional automated welding equipment will make welding more challenging.

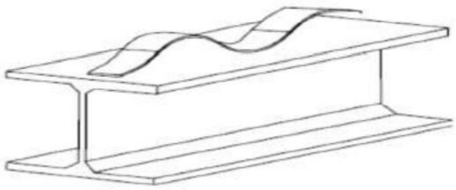

Fig.10:-*Waveform Strips*

T-CONNECTORS

This connector consists of a normal T-section piece that has been two fillet welds to a H or I section. Vertical separation between the steel section and the concrete can be avoided by using a T-section with a greater cross section than a single strip. The T-connector has a highly favourable behaviour. Due to its relatively tiny area, the front of the T is under a lot of beating stress. Local concrete crushing occurs, producing a performance that is almost plastic. T-connectors have a load capacity that is comparable to that of oscillating perfobond strips, but these connectors have far more ductility. The load capacity and ductility of this kind of connector noticeably increase when used in fiber-concrete, lightweight concrete, or a higher strength concrete.

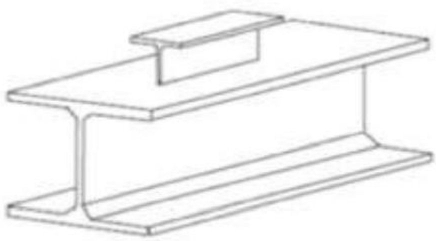

Fig.11:- *T-Connector*

CHANNEL CONNECTOR

Due to the very dependable conventional welding technology used to weld these connectors, channel connectors may not require inspection procedures like bending tests of headed studs. A stud shear connector has a lower load bearing capacity than a channel shear connector. This makes it possible to replace a lot of headed studs with a small number of channel connectors.

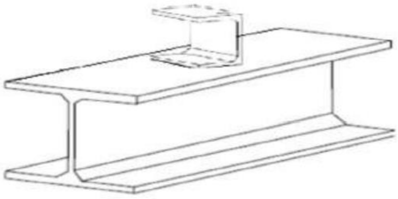

Fig.12:- *Channel Connector*

PYRAMIDAL SHEAR CONNECTORS

It is anticipated that a pyramidal shear-connected steel plate concrete composite slab will have sufficient bending strength and flexural rigidity to withstand loads encountered during and after construction. A bottom steel deck and concrete are connected by pyramidal shear connectors to form a TSC composite slab. When applying a TSC composite slab to a bridge deck subject to traffic loads, the fatigue problem should be taken into consideration during design.[7]

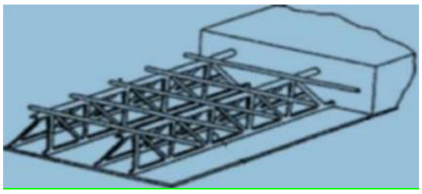

Fig.13:- *Pyramidal Shear Connector*

RECTANGULAR-SHAPED COLLAR CONNECTORS

The collar that spans the timber beam and is welded together at adjacent wings makes up this connecting device. A rubber layer is put at the collar-beam interface.

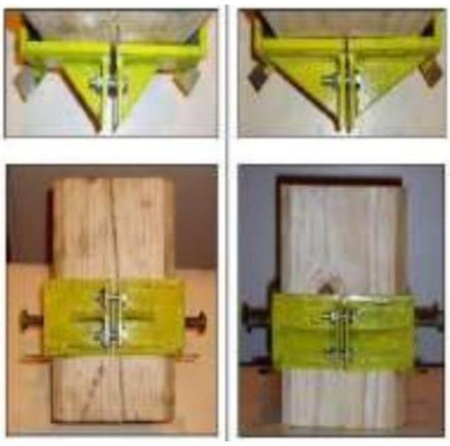

Fig.14:-*Rectangular-shaped collar connectors*

6.DESIGN OF SHEAR CONNECTORS

6.1Elastic Design

Assuming that the ultimate load is obtained when the maximum shear force of any shear connectors equals its shear resistance, this method is often employed for stiff or non-ductile shear connectors. The distribution of the longitudinal shear forces is followed in the optimization design of the shear connector configuration.

As a result, the following equation is used to calculate the longitudinal shear per unit length at the interface between the concrete slab and steel girder:

$$\tau = \frac{V(x)S}{I\ t}$$

where S is the first moment of area taken at the steel-concrete interface, I is the second moment of area of the composite section, t is the width of the top flange of the steel girder, and V(x) is the longitudinal shear force at cross section x.
The total longitudinal shear force caused by external loads should not be greater for a given unit length than the shear resistance offered by connectors. Hence, the quantity N of shear connectors at a given length can be calculated as follows:

$$N \geq \frac{\tau t}{Pu}$$

6.2Plastic Design

Each shear connector in the plastic design is considered to be in its final state and to be able to withstand the same shear force. This approach divides the composite beam into several zones based on the distribution of the bending moments at the maximum and zero moment positions, as shown in Figure 15. The required shear force for the zones with positive bending moments is calculated as follows:

$V = min(A_s f_y, A_c f_c)$

The required shear force is calculated as follows for the zones from the maximum positive bending moment and maximum negative bending moment:

$V = min(A_s f_y, A_c f_c) + A_{st} f_{yt}$

Assuming that each shear connector has a shear capacity of Pu, the necessary number of shear connectors, N, can be calculated by:

$$N \geq \frac{V}{Pu}$$

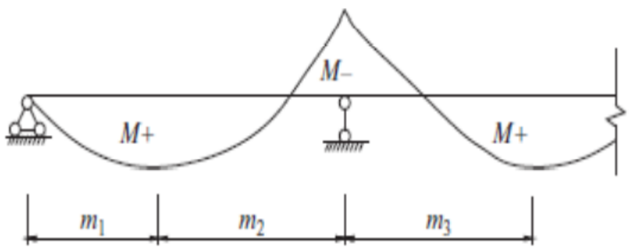

Fig.15:- *Bending moment distribution*

7.TESTING A SHEAR CONNECTOR

To assure the quality of the stud weld, Euro code recommends two quality tests, namely

7.1Ring Test

A 2 kg hammer is simply used to tap the side of the stud's head during the ring test. After striking, a ringing tone denotes good fusion, whereas a flat tone denotes poor fusion. The welder or the welder's companion must do this inspection on every stud.

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7.2Bend Test
With a 6 kg hammer, a stud's head must be shifted laterally by around 1/4 of its height in order to pass the bend test. After that, the weld should be examined for cracking or a lack of fusion.

8 PERFORMANCE OF SHEAR CONNECTORS: EXPERIMENTAL CASE STUDY
The overall behaviour of steel–concrete composite structures highly depends on the shear behaviour of the connectors. So, several studies were carried out in this area with push out test.

Push-Out Test
The following procedures were used to test each push-out specimen. Unless there were issues during testing, specimens were continually loaded (i.e., they were not unloaded and loaded again). If used, a normal load was first applied. The applied normal load was typically 10% of the applied axial (shear) load, although in rare situations it may be 5% or 20%. Once a load of around 80% of the anticipated capacity was attained, the axial load was then applied in 5-kip increments. The load-slip curve turns nonlinear around this load. Thereafter, load was supplied until the slip rose by a preset increment, and slip control was used. A automated data acquisition system was used to record the load and slip readings. These were taken every four minutes or so. This is about the time it takes for the readings to "settle" and the specimen to deform under a specific force. If the measures settled rapidly, less time was given. Each time the specimen was loaded, no more than 5 kips may be added. As a result, adding the force necessary for the specimen to slip the correct amount may have taken two to three minutes. In this instance, intervals between measurements were permitted to exceed four minutes. In any case, the goal was to gauge how much weight the specimen could support while moving a certain distance. Throughout the testing, observations of the specimen behaviour were documented. When specimens could no longer withstand the load or when severe displacements were noticed, they were loaded to failure. Measurements taken during testing were entered into a spreadsheet to create a load-slip graphic.


Fig.18:*-Push-out test setup*

8.1Shear Performance of Transverse Angle Shear Connectors
A study was conducted by Haibo Jiang et al.[2] which compared transverse angle shear connector with that of longitudinal shear connector.

Transverse angle shear connectors were used in some pre-stressed concrete box-girders with corrugated steel webs (CSWs) to get around the bottom slabs' concrete casting barrier. To test the shear performance of transverse angle shear connectors, seven large-scale push-out specimens with various shear connector heights and spacing were used. We looked at specimens' failure modes, load-slip correlations, ultimate shear strengths, initial stiffness, and ductility. This study reveals that the shear strength of transverse angle connections was influenced by both the connector height and spacing. Transverse angle shear connectors demonstrated apparent strength improvement and acceptable ductility when compared to conventional longitudinal PBL shear connectors.

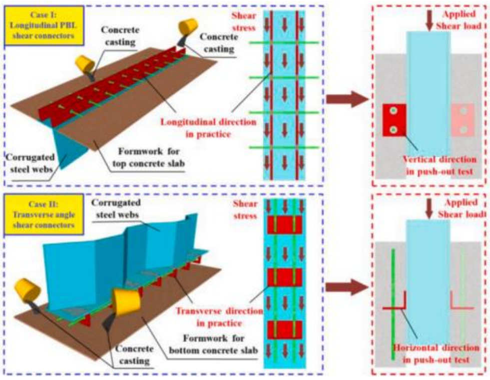

Fig.19:- *Arrangement of transverse angle shear connectors in composite girders*

For the connection between the bottom flanges of the CSWs and the bottom concrete slab, fresh concrete cannot be easily cast between adjacent longitudinal PBL connectors. One alternative solution is to arrange the angle connectors in the transverse direction. This orientation results in a better casting quality, as well as an easier casting operation. Due to the orientation change of the shear connectors, the shear behaviour of the interface between the CSWs and the bottom concrete slabs depended on the shear capacity of the transverse angle connectors. The experimental program consisted of seven large-scale push-out tests, including six transverse angle connector specimens (horizontal direction in the push-out specimens) and one reference specimen with traditional longitudinal PBL shear connectors (vertical direction in the push-out specimens).The height of shear connectors varied from 100 mm to 160 mm, while the spacing of shear connectors ranged from 250 mm to 450 mm. Series A specimens have one connector per slab, and the connector height was chosen as 100 mm, 125 mm and 160 mm. Series B specimens have two connectors per slab, with the same shear connector dimensions as specimen A-160.The reference specimen (specimen RS) also had the same shear connector dimensions as specimen A-160.

OBSERVATIONS

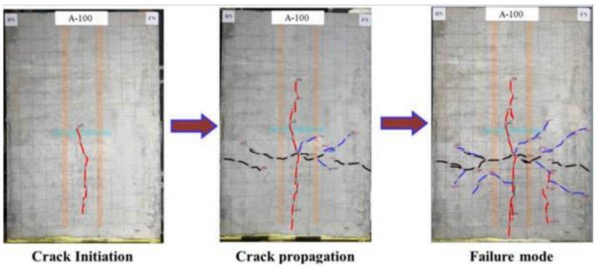

Fig.20:- *Typical crack propagation*

On the surfaces of the concrete slab, several cracks were observed. These cracks could be classified as three types, including the vertical cracks (in red), the horizontal cracks (in black), and the diagonal cracks (in blue). Typically, the vertical cracks were formed first adjacent to the connector reinforcements. This type of crack was mainly related to the expansion occurred in horizontal direction resulted from the vertical applied loading. With the load increasing, the out of-plane bending moment of the slab led to the horizontal cracks which was also demonstrated by that the cracks through partial thickness of the slab. Lastly, the splitting action in the vertical direction may also result in the diagonal cracks below or beyond the connectors. For Series A specimens more cracks occurred in specimens with a taller connector flange during the experiments. When a comparison was made between the Series B specimens (B-250, B-350 and B-450), no horizontal crack was found between the two connectors in the specimen B-250.One of the possible reasons for this phenomenon was that an interaction-zone was formed between the connectors. This zone did not appear to be formed at larger connector spacing. Thus, a fully developed horizontal crack can be seen in both specimens B-350 and B-450. This may be the explanation for the most serious spalling of concrete in specimens B-450.As for the reference specimen (RS), vertical cracks along with the connector, horizontal cracks adjacent to the connector reinforcement, and diagonal cracks below the connector were displayed.

Applied shear-slip relationship

At the beginning of loading, the steel beam began to slip, exhibiting a linear relationship between the applied load and vertical slip. At the same time, an out-of-plane bending moment was induced on the concrete slab, which results in the separation (horizontal dilation) between the steel girder and concrete slab. Once the tensile stress induced by bending moment or splitting action of connectors were larger than the ultimate tensile strength of concrete, cracks were found in the slab. The specimens then expressed a non-linear behaviour. With the forming of new cracks and the propagation of initial cracks, the slope of curves became smaller and smaller until reaching the ultimate load. At the post-peak load stage, the load dropped slightly, with an apparent increase of displacements.

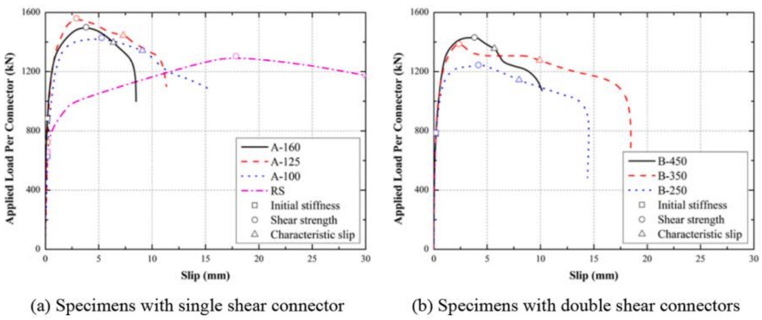

Fig.21:- *Applied load-slip relationship of push-out specimens*

Effect of shear connector height

As shown in Figure 21 a, the slope of the load-slip curve in the elastic range is influenced by the shear connector height when comparison was made among the Series A specimens. This influence is illustrated by the value of stiffness (K). When the shear connector height varied from 100 mm to 160 mm, the initial stiffness was varied from 3138 kN/mm to 4416 kN/mm. This difference suggests that the initial stiffness of specimens is slightly improved with taller shear connectors. Moreover, comparing the ultimate shear strength of specimens A- 125 with that of specimens A-100, a 25% increase of connector height resulted in an increase of shear capacity by nearly 10%. This indicated that the connector height made a minor influence on the shear capacity of transverse angle connectors. However, when the connector height was changed from 125 mm to 160 mm, there was a minor drop in shear capacity. This result can be explained by the serious failure of concrete slab for specimen A-160. Additionally, a faster descending of the applied load was seen in specimens A-125 and A-160 compared with the corresponding 100- mm-height connector specimens. This indicated that the ductility of the latter is better than the former.

Effect of shear connector spacing

The concrete between the connectors in specimen B-250 may have been confined. When the distance of shear connectors was 450 mm independent development of horizontal crack was observed. This suggested that the group connector effect was negligible, which meant that the interaction area was quite small. With the full development of a crack in slab concrete, serious spalling of concrete occurred. The initial stiffness of the specimens was found to be proportional to the number of shear connectors. The variation of shear connector spacing in specimens led to different failure modes. As a result, specimens with larger connector spacing reached a higher shear capacity.

8.2 Shear Performance of Adhesive Shear Connectors

Traditional shear connectors are mainly made of metal materials and can be in the form of stud, structural steel elements, bent-up bar and perfobond leiste (PBL) shaped shear connector. Although metal shear connectors are widely used due to their advantages in the aspects of mechanical properties, welding and construction, some studies have found the following disadvantages:

- Metal shear connectors arranged at intervals will lead to discontinuous shear stress transmission at interface
- Metal shear connectors tend to cause local stress concentration, leading to potential initial cracks in the concrete at the front end thus affecting the durability of structure
- Residual stress in welding process will affect the fatigue life.

To overcome the above demerits non-metallic shear connectors are used. The work on adhesive shear connectors by Yulin Zhan, Mengjun Duan, and colleagues uses epoxy resin and magnesium phosphate cement (MPC) as the adhesive materials, respectively.The findings indicate that the epoxy resin shear connector has a higher shear strength than the MPC one. Epoxy resin shear connectors have an average shear strength of roughly 4.07 MPa, which is higher than the average shear strength of traditional stud shear connectors, which is 3.0 MPa, suggesting that they have an equal capacity for shearing at the interface to traditional stud shear connectors. MPC shear connectors typically fail due to the debonding of the binder and steel, whereas epoxy resin shear connectors typically fail due to the strength of the concrete or adhesive layer.

Suggestions for the application of adhesive shear connectors

Since the failure of adhesive shear connectors is still the brittle one, it is insufficient to use it as shear connector alone. Thus, the adhesive shear connector can be combined with mechanical shear connectors, such as the combined shear connector constituted by the adhesive shear connector and stud or PBL one. The advantages of this method are:

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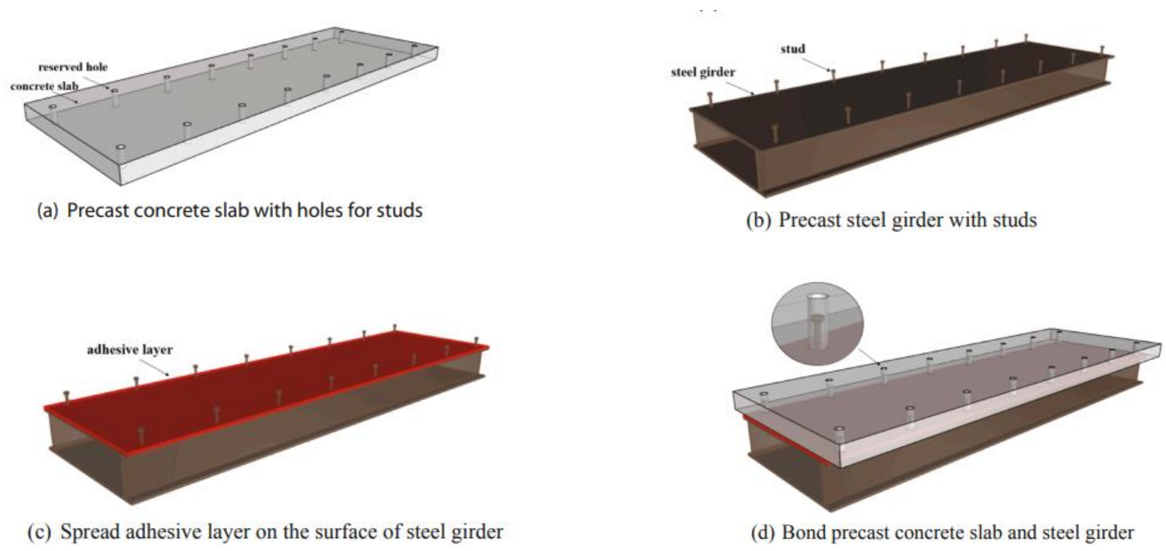
• Adhesive shear connectors can remedy the discontinuity of shear force transmission between studs or PBL and the local stress concentration. Moreover, combined shear connector can enhance the ductility of the structure and make it safer.
• Adhesive shear connectors can fill the gap between the steel girder and the concrete bridge deck, which can prevent the moisture in the air from infiltrating into the structure, thus enhancing the durability of the structure. Such a connector also includes noise reduction, sound insulation, and shock absorption capabilities.

According to certain researchers, the steel girder's structural noise can be decreased in the steel-concrete composite bridge by applying damping materials to the steel girder's surface. Damping materials are not only cheap, practical, and efficient when utilised to reduce vibration and noise in steel-concrete composite bridges.• Combined shear connectors are more flexible in the rapid replacement of thin pavement layer in orthotropic steel bridge deck, hence accelerating the construction.
• As the adhesive shear connector bears part of the shear force, the spacing of studs (ds) can be increased, or studs with small height and diameter can be used to reduce the thickness of concrete slabs (hc). Such kind of adhesive shear connector has not been widely used in practical bridge engineering. The construction method of specimens was (1) welding stud; (2) applying adhesive; (3) pouring concrete. The test results showed that this was a feasible application method. Application method of combined shear connectors can be completed by reserving holes for studs on precast concrete slab.

Construction process can be divided into the following five steps:
a. Precast concrete slab with holes for studs.
b. Precast steel girder with studs.
c. Spread adhesive layer on the surface of steel girder.
d. Bond precast concrete slab and steel girder and ensure studs are in the reserved holes.
e. Pour cement mortar into the reserved holes to make studs and concrete slab form a whole.
The layout of construction method is shown in Figure 22



(a) Precast concrete slab with holes for studs
(b) Precast steel girder with studs
(c) Spread adhesive layer on the surface of steel girder
(d) Bond precast concrete slab and steel girder

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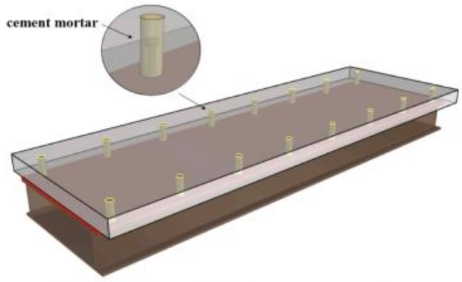

(e) Pour cement mortar into the reserved holes

***Fig.22:-** Layout of the Construction method*

9.NOVEL SHEAR CONNECTORS

Many experimental and numerical investigations have mostly concentrated on the behaviour of single shear connectors, although under in situ stress conditions, the behaviour of multiple shear connectors may differ accordingly. In addition, a number of new types of shear connections have been developed to address the shortcomings and limitations of the earlier models. By securing the free end of the C-channel outside the specimen with bolts and conducting research using the common pushout testing, Yan et al. created a new type of improved C-type channel (EC) shear connections.

According to the test results, ECs improved the C-channel connections' ultimate shear resistant behaviour and revealed subsequent failure of bolts and C-channel connectorsTo further improve the mechanical efficiency of the hogging moment region in composite beams, Nie et al. created a new type of T-shaped uplift-restricted and slip-permitted connector (URSPT) with foamed plastic. This connector is intended to stop concrete slab separation from the steel beam and delay concrete cracking. The push out test was performed to evaluate the effectiveness and performance of the shear connectors. Push-out testing revealed apparent slip deformation of the URSP-T connector, and the foamed plastics around the connectors significantly decreased their slip capability.

The difficulties of applying shear connectors for columns were taken into account by Odenbreit et al. as they created a novel shear connection for composite beams. For instance, it is acknowledged that the shear stud geometry makes the application of reinforcement challenging and the manipulation of the column more challenging. With the capability for a fully automated manufacturing process and additional high resistance, stiffness, ductility, and production efficiency requirements, a new type of advanced flat shear connection has been created. The standard reinforcing bars used in the new shear connector design are welded in a specific pattern to the steel profile flanges.

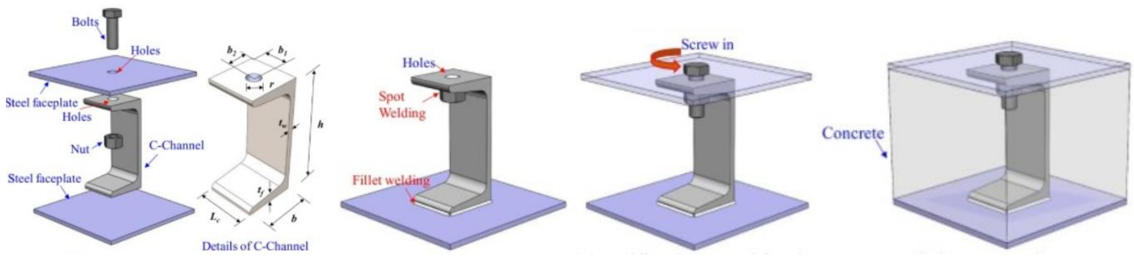

***Fig.23:-** Enhanced C-Type Channel (EC) Shear Connectors*

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10.EFFECTS OF DIFFERENT PARAMETERS ON BEHAVIOR OF COMPOSITE BEAM WITH BOLTED SHEAR CONNECTORS.

10.1Effect of Different Types of Post-Installed Shear Connectors

Kwon et al. are the only ones looking into a wide variety of other kinds of post-installed shear connectors. only three varieties were selected: The Adhesive Anchor (x), High-Tension Friction-Grip Bolt (HTFGB), and Double-Nut Bolt (DBLNB) strength levels are higher than those of traditional welded studs. These post-installed connectors performed much better in static push tests than traditional welded studs in terms of strength capacity. The absence of welds in the installation of these three post-installed shear connectors is largely responsible for their remarkable strength performance The HTFGB connector has the highest initial rigidity and nearly no slip during the early loading stages. This is due to the HTFGB connector's first frictional shear transmission at the steel-concrete interface. Consequently, using an HTFGB connector, a composite beam can achieve full composite action without slip at the steel-concrete interface before friction is overcome. Due to an enlarged hole that increases the HTFGB connector's slip capacity, it also demonstrated a noticeably higher slip capacity than the DBLNB and HASAA connectors. This allowed for more load redistribution among the shear connectors, increasing the beam's strength and deformation capacity. Also, compared to HTFGB and HASAA connector specimens, the DBLNB connector specimens showed reduced concrete crushing, which may be explained by the wide bearing surface of the nuts embedded in the concrete block. The specimen with the HTFGB connector had greater overall ductility compared to the specimens with the DBLNB and HASAA shear connectors. The HTFGB has greater benefits than the DBLNB and HASAA, it is therefore concluded.

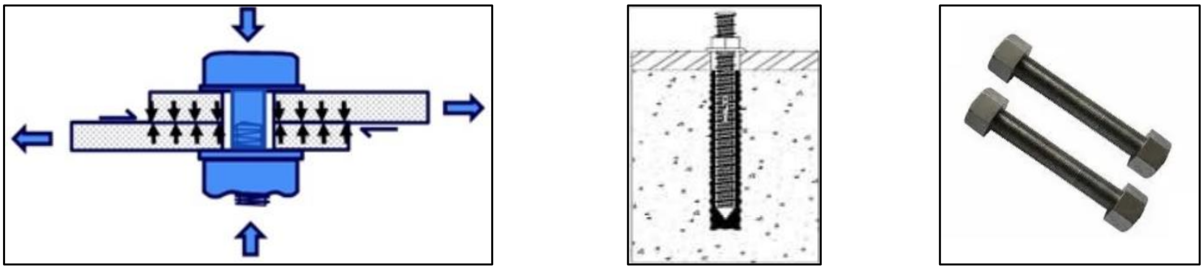

Fig.24:- (a) HTFGB (b)HASAA (c)DBLNB

10.2 Effect of Bolt Spacing, Number of Bolts (Shear Connection Ratio) and Diameter of Bolts

The quantity of connectors in a composite beam determines its shear connection ratio. Most studies advise a full shear connection in steel-concrete composite beams since it will result in higher ultimate strengths than a partial shear connection. Kwon et al. further demonstrated that raising the shear-connection ratio boosted the composite beams' strength, stiffness, and deformation capacity. The outcome was not very significant, though, when compared to connections with varying degrees of shear and varied bolt diameters. For instance, a study by Liu et al. revealed that the ultimate strength of a beam with a bolt diameter of 20 mm Additionally, a beam with a bolt diameter of 16 millimeters and a degree of shear connection ratio of 0.85 is comparable to this one. As a result of this discovery, it may be possible to cut building costs by using smaller bolt sizes. Chen and co. cited an investigation into four distinct bolt spacings: in terms of the kinds of failures, 300 mm, 600 mm, 900 mm, and 1200 mm. In this examination, the disappointment mode changes from steel yielding or substantial pulverizing to blasted shear connector shear disappointment when the distance is raised to 600 mm, and shear disappointment turns out to be more serious at 900 mm. This indicates that the connectors have already reached their maximum shear level prior to concrete slab crushing or steel yielding. As a result, the composite beam's stiffness gradually decreases and its midspan vertical displacement increases as bolt spacing increases.

A higher ultimate strength must be possible if a partial shear connection ratio is adopted to reduce building expenses. In a research for retrofitting non-composite steel bridge girders with post-installed shear connections, Kwon et al. found that all composite beams with shear connection ratios greater than 30% had ductility factors greater than 2. They also concurred that the ultimate strength of the composite beam is over 90% of the complete degree of shear connection ratio at 30% shear connection ratio, demonstrating the effective application of partially composite beam. Moreover, the use of partial shear connections in composite beams allows for initial stiffness that is nearly equal to that of full shear connections. In order to retrofit existing non-composite steel bridge girders using post-installed shear connectors and to prefabricate new composite beams, a minimum shear-connection ratio of 30% is advised.

10.3 Effect of Locating Shear Connectors Near Supports

The placement of shear connectors is a crucial component to look at at partial shear connection ratio. According to Oehlers and Sved, the slip at the steel-concrete interface can be decreased at focusing shear connectors close to zero-moment zones when the beam reaches its full flexural capacity. This is because beams that are simply supported and have shear connectors concentrated close to the supports are likely to have larger deformation capacities than beams that have shear connectors evenly distributed throughout the span. In order to maximise the slip resistance, it was advised that shear connections only be positioned close to supports or zero-moment areas for partial shear connection.

A beam with shear connectors positioned close to the supports in a finite element model revealed much reduced slide at the steel-concrete contact. Compared to shear connectors that are evenly distributed, the partly composite beam's deformation capacity is significantly increased by shear connectors that are concentrated close to the supports. This shows that before any shear connector fails, the composite beam with shear connectors clustered close to the supports can deflect more than the beam with uniformly dispersed shear connectors. As a result, post-installed shear connectors should be concentrated close to zero-moment zones rather than dispersed evenly across a beam's length. This will increase the slip resistance and overall ductility of strengthened partly composite beams.

10.4 Effect of Concrete Panel Configuration

Precast concrete was used in the design of the composite beam with bolted shear connector because the elements can be produced in a controlled environment, making quality control and maintenance easier than with cast-in-situ concrete. The width of the space between the concrete panels is a crucial factor in concrete panel configuration. The width of the space between concrete panels was varied in a finite element modelling study from 0 to 4 mm. When the width of the space between the concrete panels was zero during initial loading, the beam behaved completely compositely. The beams' initial rigidity was drastically lowered when the gaps between the concrete panels were added. Hence, it was advised that in order to achieve sustainable concrete beams, the gaps between the precast concrete panels must be minimised during the assembly of the beams or filled in the construction.

This is due to the fact that the composite beam will behave fully compositely during first loading if there are no gaps between the precast concrete panels. The composite beam will behave fully compositely

10.5 Effect of Concrete Strength and Grout

One of the crucial factors to take into account when designing the composite beam is the concrete strength and grout in precast concrete slabs. The majority of researches have shown that the ultimate strengths of composite beams grow together with the compressive strengths of concrete, though not noticeably. For instance, a study by Liu et al. revealed that the ultimate strength of the beam only increases by 5% as concrete strength rises from 42 to 70 MPa.

Nonetheless, it is claimed that for lower slab concrete grades (less than C30), concrete splitting and crushing predominate, whereas for higher slab concrete grades, shear stud strength predominates. As a result, it is desirable to construct the composite beam with a higher concrete strength. The shear connectors inside the concrete slab of a composite beam are covered with grout. According to the previous investigation, concrete grout with a similar compressive strength to that of the concrete had no appreciable impact on the ultimate strength of the composite beam. However, the grout in front of the connectors may undergo significant crushing strains during loading if the grout strength is lower than the strength of the shear connector.

According to a study by Pathirana et al., the grout suffered more severe damage than the concrete, with more cracks developing on the existing material. In order to boost the strength of the composite beam, a stronger concrete grout would be preferred.

11 APPLICATIONS OF SHEAR CONNECTORS

A crucial method for creating strong connection points that can withstand shear loading is the use of shear connectors. They are utilized in numerous applications including, yet not restricted to:

1. Establishing a connection between upright steel beams and a concrete foundation Interfacing load bearing pillars to a substantial deck in multi-story structures
3. securing steel beams to composite slabs in overpasses and other small to large-scale bridges enforcing sidewalks and roads and avoiding excessive freeze damage securing concrete or composite ship floors to steel decking securing interior ceiling materials to metal roofing

11.1 BUILDING APPLICATIONS: Ground Floor Slabs

A reinforced concrete ground slab needs movement joints to be divided into bays. Shear force is transferred from one slab to another via DSD shear connectors, which also serve to avoid differential settling. DSDQ shear connectors should be utilised when adjacent bays have varied sizes because this will cause movement to occur in both directions.

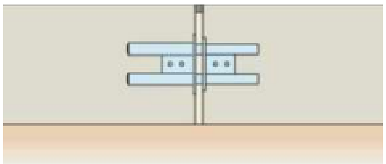

Fig.25:*-Shear connectors in ground floor slab*

Suspended Floor Slabs
Connectors should be positioned in suspended slabs at locations of contra flexure where there is little to no bending moment and the greatest shear force.

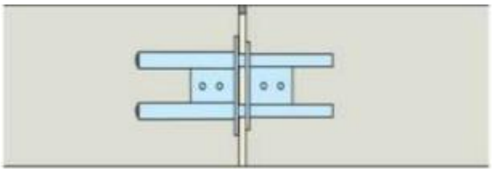

Fig.26:*-Shear connectors in suspended floor slab*

Structural Movement Joints in Frames
In framed constructions, a structural movement joint is frequently required to separate one building component from another. A two-column line is typically the result of traditional practice. DSD shear connections not only increase the floor area, but they can also reduce costs. and expedite construction.

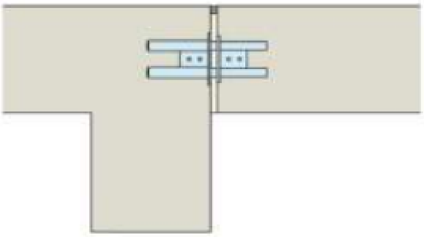

Fig.27:*- Shear connectors in Frames*

Beam to Wall or Slab Connections
Corbel and half-lap joints are challenging to design and expensive to build. DSD shear connections make design and construction easier while improving detail.

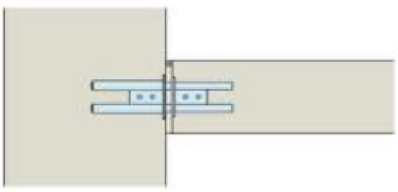

Fig.28:*- Shear connectors in Beam to wall connection*

11.2 CIVIL ENGINEERING APPLICATIONS
Movement Joints in Carriageways
In carriageway joints, DSD shear dowels are used to transfer high shear pressures caused by concrete traffic loading and eliminate differential settling.

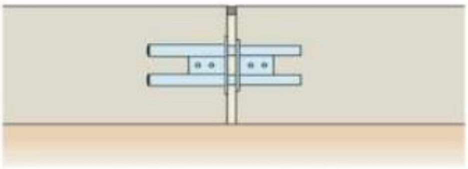

Fig.29:- *Shear connector in carriageway*

Bridge Abutments

At bridge abutments, DSD shear connectors are positioned vertically to secure the bridge deck to the abutment. In addition to being simple to install, DSD shear load connectors enable jacking up of the bridge deck for bearing replacement.

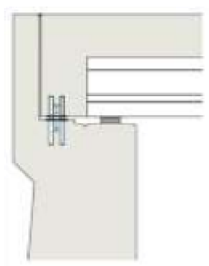

Fig.30:-*Shear connector in Bridge abutment*

Joints in Parapets

A quick and affordable method of joining the pieces is to use DSD in the vertical joints of parapets. The DSDQ increases the joint's ability to rotate significantly while maintaining its ability to shear horizontally.

Diaphragm Wall/Slab Connections

The process of joining road slabs to diaphragm walls can be challenging and expensive. There are numerous issues on the job site when forming recesses or inserting post-fixed dowels into site-drilled holes. A practical solution is provided by DSD shear connectors.

The components of the sleeves are fastened with nails to plywood formwork that is firmly fastened to the reinforcing cage. The plywood is taken off after excavation is complete to reveal the faces of the sleeves. Now that the slab is ready to be supported, the dowel components can be inserted.

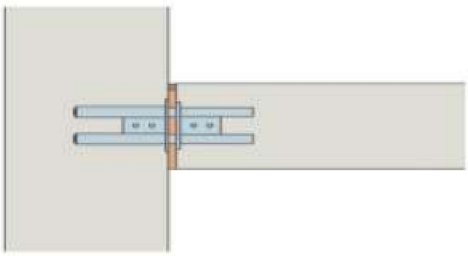

Fig.31:- *Shear connector in diaphragm wall connection*

Contiguous Piled Wall/Slab Connections

Similar to the construction of diaphragm walls, double dowel shear load connections (DSD shear connectors) are used to transfer shear load from a slab to a pile.

2 CONCLUSION

Shear connectors helps to join two materials and they will act as a single unit. When compared to headed stud shear connectors, the composite beam system can use bolted shear connectors to achieve 95% of the shear resistance under static loads. Embossed Steel Plate (ESP) shear connector specimens had higher resisting capacities than studed shear connector specimens. It was therefore clear that the ESP shear connector had a significantly more durable design and a stronger bond with the concrete. When compared to the headed stud, the ESP was more rigid. Bolted shear connectors cannot outperform headed stud shear connectors in terms of shear resistance.

Its fatigue strength is noticeably higher than that of the composite beam with headed stud shear connectors, which is crucial for strengthening bridges. The perfo-bond connection web and T-perfo-bond connectors were created to combine the substantial strength of a block type connector with some ductility and uplift resistance resulting from the holes. For similar longitudinal plate geometries, the resistance and stiffness of this type of connectors are generally higher than that of the perfo-bond connectors Adhesive shear connector such as epoxy resin shear connector possesses higher shear strength, smaller slip, and a higher degree of stability than those of traditional stud shear connectors. Therefore, it can be applied as a new type of shear connector or be used in combination with the traditional mechanical shear connectors.

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