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Deploying FRP Optimally in the Process of Strengthening Concrete Structures

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Abstract
FRPs are lightweight, durable, and resistant materials that are easily available to engineers today. FRP materials are insulated in magnetic environments and do not have corrosion problems, so by using these materials, the corrosion problem of concrete structures can be avoided. Also, these materials have superior characteristics such as high tensile strength, which makes their use as reinforcement of concrete structures suitable. It should be mentioned that, like any material, FRPs have weak points such as sensitivity to fire and weakness in bearing compressive stresses, as well as high price. In examining the effect of the installation angle of the GFRP rod; It was found that the shear reinforcement of reinforced concrete beam by NSM method with the same number and the same installation distance of GFRP rods, the arrangement of the rods with an angle of 45 degrees, has the greatest effect compared to the angles of 60 and 90 degrees It was also found that with the same amount of GFRP and the same installation distance, the arrangement of GFRP bars with an angle of 60 degrees is more effective than 90 degrees. Investigating the effect of the number and distance of GFRP rod installation showed that in the shear strengthening of the reinforced concrete beam by NSM method with the same installation angle of GFRP rod, using a rod with smaller dimensions and less distance has a greater effect on the efficiency of the reinforced beam.

Keywords: FRP, Concrete, Optimisation, Earthquake

1. Introduction

Composites or multi-structural materials or new age flower straws are a category of advanced materials in which the combination of simple materials is used to create new materials with superior mechanical and physical properties (Sun *et al*., 2024) [42]. Constituent components retain their characteristics, do not dissolve in each other, and do not mix (Farrokhirad & Gheitarani, 2024) [11]. The use of these materials has been customary throughout history. Among the first man-made composites, we can mention straw and mud bricks, in which straw reinforcement was used. When these two are mixed, a product is obtained that is much more durable and resistant than both the primary materials, i.e. mud and straw (Sadigh Sarabi, M., *et al*., 2023a).

The boats that the Indians built with bitumen and bamboo and the ovens that were made of mud, glass powder, and goat wool and found in different regions of our country are also among the first composites (Dehghan S. *et al*., 2024). The oldest example of composites is related to adding straw to mud to strengthen mud and making resistant bricks for use in buildings (MM Norouzian & N Gheitarani, 2023) [27]. This work dates back to 4000 years before Christ (Dehghan S., 2024a) [8]. In this case, straw plays the role of reinforcement, and flower plays the role of background or matrix Bam citadel, which is a masterpiece of Iranian architecture, has been a clear example of the use of composite technology in the past centuries (Dehghan S., 2024b) [7]. Another example is the reinforcement of concrete by steel rods (Zakerhaghighi *et al*., 2015) [44]. In reinforced or reinforced concrete, metal rods create the necessary tensile strength in concrete, because concrete is a brittle material and has little resistance to tensile loads. In this way, concrete is responsible for bearing compressive loads and steel rods are responsible for bearing tensile loads (Aghazadeh, M. *et al*., 2018) [3].

Many industrial needs, such as space, reactor, electronics, construction, and transportation industries, cannot be met using conventional materials and require extensive changes in properties (Sadigh Sarabi, M., *et al*., 2024a) [35]. Therefore, the use of composites has solved many problems (Naghibi Iravani, S., *et al*., 2024b) [29]. The history of fiber-reinforced polymer materials goes back to the 1940s in defense industries and especially aerospace applications (Gheitarany, N., *et al*., 2013b). For example, in 1945, more than 7 million pounds of fiberglass were used specifically for the military industry. Later, due to their merits, they entered the public industries as well (Norouzian & Gheitarani, 2024) [32]. Polymer-based composites are the most important category of composites. A wide range of industries, such as high-end industries, such as the production of aircraft parts, to low-end industries, such as the production of sinks, are produced from polymer-based composites, and for this reason, they are considered the largest subset of composite materials (Sadigh Sarabi, M., *et al*., 2023b).

Following the deterioration of infrastructure structures and the need to strengthen structures to meet strict design requirements, during the last two decades, there has been a lot of emphasis on the repair and retrofitting of structures around the world (Sohrabi, S., 2024b) [40]. On the other hand, seismic improvement of structures, especially in earthquake-prone areas, has become very important. In the meantime, the techniques of using FRP composite materials as external reinforcement due to their unique characteristics, including high strength, lightness, chemical resistance, and ease of implementation, have become particularly important in strengthening and revitalizing structures (Sadigh Sarabi, M., *et al*., 2024b). On the other hand, these techniques are particularly attractive due to their quick implementation and low costs. FRP composite materials were initially used as bending strengthening materials for reinforced concrete bridges and also as encapsulation in reinforced concrete columns; but following the initial research efforts, since the mid-1980s, a lot of development has been observed in the field of using FRP materials in the retrofitting of various structures (Sadigh Sarabi, M., *et al*., 2024d) [34].

The number of applications of FRP materials in retrofitting, repairing, or improving structures has increased from a few cases 10 years ago to thousands of cases now. Various structural components including beams, slabs, columns, shear walls, connections, chimneys, arches, domes, and trusses have been strengthened by FRP materials (Ghadarjani *et al*., 2013a). FRP systems are used to improve a damaged structural member to strengthen a healthy member or to fix problems under construction (Naghibi Iravani, S., *et al*., 2024a) [28]. Currently, a large number of researchers and structural industry researchers around the world are investigating, studying, and conducting tests on strengthening structures with FRP composites. In these 35 years, the use of this method has not been limited to concrete structures and has been used for all kinds of masonry, wooden, and steel structures (Maleki, M., *et al*., 2024) [25].

During this time, many researchers in these three continents have paid attention to the development of the use of FRP materials, and the result of their efforts is the compilation of various regulations. In the last ten years, the Society of Engineers of Japan has presented several reports on how to design FRP systems (Norouzian, M. M., 2024) [31]. At the same time, in Europe, the International Organization of Concrete Structures has presented a collection of the principles of strengthening and designing concrete structures with FRP. The Canadian Standards Association has also compiled similar collections (Ghadarjani *et al*., 2013b). In the United States of America, this task has been assigned to the American Concrete Association, which committee 440 has compiled seven regulations and design instructions (Norouzian M. M., *et al*., 2024) [31]. The need to strengthen and increase shear capacity in many reinforced concrete members in old or new structures is necessary. Among the various methods of shear strengthening, the use of FRP composite materials in a continuous or discontinuous form is one of the proposed methods in this field, considering the technical advantages and economic justification (Norouzian, M. M., & Sarabi, 2023) [33].

One of the methods of shear strengthening of concrete members is the method of embedding FRP materials near the NSM surface and placing FRP materials in the grooves created on both sides of the reinforced concrete beam (Karimimansoob *et al*., 2024a) [20]. The basis of the embedding method near the NSM surface is to stick FRP materials in the grooves created on the concrete surface. The NSM method is effective in increasing the shear and bending strength of concrete members. The embedding method near the surface is one of the new methods of reinforcing reinforced concrete beams, which have been strengthened by shear using FRP materials (Zaker Haghighi *et al*., 2014) [43]. As a result, the need to conduct more research in this field, especially in our country, is quite evident.

2. Theoretical

What is FRP? FRP is a type of composite material consisting of two parts of fiber or reinforcing fibers surrounded by a polymer resin matrix (Khanian, M., *et al*., 2013) [22]. The most basic form of a composite material is the form in which two components are combined and produce a material with properties that are different from the properties of its components. Reinforced polymers are composed of very thin fibers that are enclosed by the base material (Dizaji, A. *et al*., 2023) [10]. The fibers have different types and are produced in the form of short pieces, long threads, and woven fabrics. In FRPs, the background plays the role of protecting the fibers and transferring the stress between them, and the fibers play a load-bearing role. FRP parts are made by various industrial, semi-industrial, or handmade methods. Reinforcements (fibers), (Kahvand, M., *et al*., 2015) [19]. FRP materials consist of two basic components; reinforcements or fibers and resin (base material). Fibers, which are elastic, brittle, and very resistant, are considered to be the main load-bearing component in FRP materials (Aghazadeh, M. *et al*., 2019) [1].

Depending on the type of fiber, its diameter ranges from 5 to 25 microns. Nowadays, due to durability, resistance, and high hardness, carbon fibers have found the most use. Glass fiber works well in dry environments, and aramid fiber is used to absorb energy and impact. In the following, a brief description of some common fibers will be provided (Naghibi Iravani, S., *et al*., 2024c) [30]. Glass fibers Polymer matrix composites reinforced with glass fibers are called GFRP. Fiberglass is a common name for polymer matrix composites reinforced by fine glass fibers. In general, 90% of polymer matrix composites are reinforced with glass fibers. Glass is widely used as a reinforcing fiber due to the following properties in this type of composites:

- Easy and quick access and cheap materials
- Simple and cheap technology for making continuous fibers from molten glass
- High corrosion resistance
- High tensile strength of about 4100 MPa (Zhang *et al*., 2024) [45].

***The types of glasses used in fiberglass are*:** The most common and cheapest is glass fiber. The letter E means electrical and an excellent insulator. Young's modulus is relatively high. S-glass: Stronger than E-glass fibers. The letter S means strength (Khodadadi, *et al*., 2024) [24]. They are used in military and aerospace applications. S+R-glass: The strongest and most expensive glass fiber with a small diameter. **C-glass**: This glass fiber is resistant to corrosion and chemical interactions and is used in the construction of storage tanks and other equipment resistant to chemical interactions (Norouzian & Gheitarani, 2023) [27].

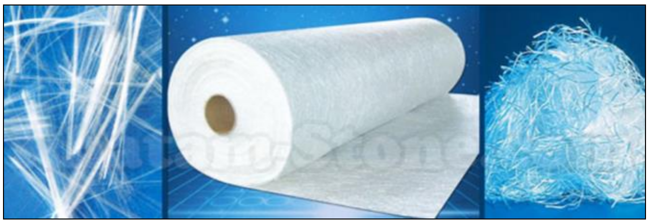

Fig 1: FRP Structure Different forms of GFRP

Carbon fibers. Polymer matrix composites reinforced with carbon fibers are called CFRP (Gheitarani, N., *et al*., 2024b). Carbon fibers, which are one of the strongest fibers, are produced by the carbonization of natural or synthetic polymer fibers at a temperature higher than 2700 degrees Celsius, or by warping organic materials such as bitumen and resin (Karimimansoob, V. *et al*., 2024c). Carbon fibers are very expensive (Aghazadeh, M. *et al*., 2017) [2]. These fibers provide a wide range of properties, thus allowing engineers to design better composites. When carbon fibers are used as reinforcement in a polymer matrix, they provide the following properties:

- High modulus of elasticity compared to steel
- High tensile strength of about 7 GPa
- The low density of about 1800 kg/m3.

High chemical neutrality (Sadigh Sarabi, M., *et al*., 2024c).
The most common base materials for making polymers with carbon fiber reinforcement are polyester, thermosets, and polyamide, among thermoplastics. Reaction with metals and the formation of brittle and brittle carbide phases, high electrical conductivity, low impact resistance, lack of efficiency in acidic environments, and high price are among the disadvantages of carbon fibers (Karimimansoob *et al*., 2024- b) [21].

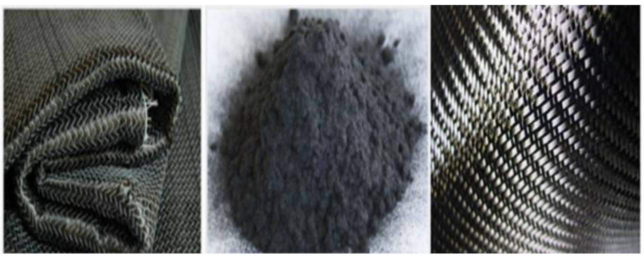

Fig 2: Different forms of CFRP

Calm down Aramid is an abbreviation of aromatic polyamide. The two commercial names of aramid fibers are Kevlar and Nomex. These fibers were first developed as a substitute for steel in rubber and then found other uses (Benzaamia *et al*., 2024) [5]. These fibers show a very high strength-to-weight ratio. Their tensile modulus is much larger than their compressive modulus. Their impact resistance is very high as a result of high tensile modulus. Aramid supports the carbon fibers and improves their properties. Combined fibers (aramid + carbon fibers) combine very high tensile strength with wear and impact resistance. The most common base materials for making aramid-reinforced polymers are thermosets such as epoxy and vinyl stryphenol (Gheitarani, N., *et al*., 2013a).
Polymers reinforced with aramid fibers are made by open, closed, and pultrusion molding. Context Many materials show very good strength when they are in the form of fibers, but to achieve these properties, the fibers must be bonded to a good substrate. The substrate holds the fibers in place and separates them to prevent wear and the formation of new surface defects. A good substrate should have the ability to change shape under the applied load, transfer the force to the fibers, distribute the stress concentration protect the fibers from damage, and prevent the propagation of cracks in the composite.
The base (matrix or resin) can be chosen from thermoplastic or thermoplastic mixtures or elastomers. Thermoset matrices harden by applying heat and no longer become liquid or liquid; while thermoplastic resins can be liquefied by applying heat and solidified by applying cold. Elastomers are intermediate between thermosets and thermoplastics. Polyester, vinyl ester, and epoxy can be mentioned as thermoset resins, and polyvinyl chloride, polyethylene, and polypropylene as thermoplastic resins. Composite materials are divided into three groups based on the type of base: Polymer base composites, metal base composites, and ceramic base composites.
Application of FRP materials. Following the deterioration of infrastructure structures and the need to strengthen structures to meet strict design requirements, during the last two decades, there has been a lot of emphasis on the repair and retrofitting of structures around the world. On the other hand, seismic improvement of structures, especially in earthquake-prone areas, has become very important. In the meantime, the techniques of using FRP composite materials as external reinforcement due to their unique characteristics, including high strength, lightness, chemical resistance, and ease of implementation, have become particularly important in strengthening and revitalizing structures (Khanian, M., *et al*., 2019) [23].
On the other hand, these techniques are particularly attractive due to their quick implementation and low costs. FRP composite materials have a wide range of applications for strengthening reinforced concrete structures in cases where conventional strengthening techniques may be problematic. For example, one of the most common techniques for improving reinforced concrete components is the use of steel sheets that are attached to these components from the outside. This method is simple, economical, and efficient; But it is problematic in the following ways:
Deterioration of adhesion between steel and concrete caused by steel corrosion - problems of making heavy steel plates in the construction site - need to install scaffolding - length limitation in transferring steel plates to the construction site (in the case of flexural strengthening of long components). FRP strips or plates can be a suitable alternative to steel plates. Unlike steel, FRP materials are not affected by electrochemical deterioration and can resist corrosion by acids, bases, salts, and similar aggressive substances in a wide range of temperatures (Sohrabi, S., 2024a) [41]. As a

result, there is no need for corrosion protection systems and it is easier to prepare the surfaces of members before gluing FRP plates and maintain them after installation than steel plates.

In addition, the reinforcing fibers in FRP can be placed in a certain position and in a specific volume ratio and direction inside the matrix to achieve maximum efficiency. The resulting materials, with only a percentage of the weight of steel, have high strength and hardness in the fiber direction. They are also easier to transport, requiring less scaffolding for installation. They can be used for places that have limited access and do not impose a significant additional load on the structure after installation. Another conventional method in reinforcing reinforced concrete members is to use reinforced concrete, sprayed concrete, or steel coatings. This method is quite effective as far as resistance, hardness, and malleability are concerned; But it increases the dimensions of the sections and the dead load of the structure.

Also, this method requires troublesome operations and evacuation of residents and potentially causes an undesirable increase in the hardness of reinforced concrete members. As an alternative, FRP sheets can be wrapped around reinforced concrete components, significantly increasing strength and ductility; Without making a big change in difficulty. An important point regarding the strengthening of members with the external use of FRP is that we should limit the degree of strengthening (ratio of the ultimate capacity of the reinforced member to the ultimate capacity of the unreinforced member) to the minimum level of safety in accidents such as fire that lead to the loss of The effectiveness of FRP will be maintained.

In this figure, it can be seen that by connecting the FRP plates to the lower face of the beam, positive bending capacity is obtained and by connecting it to the upper face of the beam, negative bending capacity is obtained. It is also possible to provide appropriate shear capacity by connecting FRP plates to the two side faces of the beam. In the failure of reinforced concrete beams reinforced with FRP plates, various failure mechanisms have been reported, including rupture of FRP plates, crushing of concrete, shear failure of concrete, and cracking at the junction of glue and concrete. It has also been shown that FRP type, thickness, and length cause different types of soft or brittle failure. Especially the mechanical properties of FRP and concrete connection area are of special importance. Meanwhile, the separation of FRP plates from concrete is a very important issue and today it attracts a lot of attention in the world.

3. Methodology

15x cm cubic samples were made during the concrete casting of the beams and were processed in the same conditions as the beams (Gheitarani, N., *et al*., 2020) [15]. The average compressive strength of these samples on the day of testing was 421 kg/cm2. Ribbed rebars manufactured by Isfahan Iron Smelting Factory have yield stress equal to 3000 kg/cm2. The FRP rebar used in this experiment has a diameter of 10 and 7 mm and a glass type with a weight of 0.12 kg/m (Gheitarani, N., *et al*., 2024c). The behavior of this material has been linear until the moment of failure, and the manufacturer has declared its maximum tensile stress and modulus of elasticity as 1200 and 55000 MPa, respectively. The failure strain of GFRP rebar is equal to 2.2%.

***The method of carrying out retrofitting*:** In the shear reinforcement of reinforced concrete beam by NSM method, by cutting the concrete surface, grooves are created on the lateral surfaces of the beam in the shear openings, and after emptying the groove of extra particles and dust, filling about half of the groove with epoxy or glue, then GFRP rebar inside the groove was placed. Finally, the other half of the groove was filled with glue to make the concrete surface flat. To use GFRP rebar with a diameter of 10 mm, grooves with a cross-sectional area of 1.4 x 1.4 cm, and to use a GFRP rebar with a diameter of 7 mm, grooves with a cross-sectional area of 1.1 x 1.1 cm were created on the concrete surface and in the desired locations.

Fig 3: Marking the location of the groove

Fig 4: Filling the groove with glue

Specifications of tested beams: NSMIL10, NSMV10, and NSMV7 beams were shear strengthened by the NSM method The amount of GFRP used in the beams is equal. The NSMV10 beam was shear reinforced with 16 GFRP bars with a diameter of 10 mm a center-to-center distance of 124 mm and an angle of 90 degrees with the longitudinal axis of the beam. In the NSMV7 beam, 32 GFRP rebars with a diameter of 7 mm a center-to-center distance of 56 mm, and an angle of 90 degrees with the longitudinal axis of the beam were used. In the NSMV10 beam, on both sides of both shear openings, the distance of the first groove from the side edge of the beam was 11 centimeters, and in the NSMV7 beam, this distance was 10 centimeters.

In the NSMIL10 beam, 16 GFRP rebars with a diameter of 10 mm a center-to-center distance of 124 mm, and an angle of 60 degrees with the longitudinal axis of the beam were used. On both sides of both shear openings, the distance of the first groove from the side edge of the beam was 5 cm at the top of the beam and 16.5 cm at the bottom of the beam. The reason for choosing a 60-degree angle is that it is easier to perform and at the same time effective. In the beams that were reinforced with GFRP rebar with a diameter of 10 mm, the dimensions of the groove were 1.4 x 1.4 cm, and in the beam that was reinforced with GFRP rebar with a diameter of 7 mm, the dimensions of the groove were 1.1 x 1.1 cm.

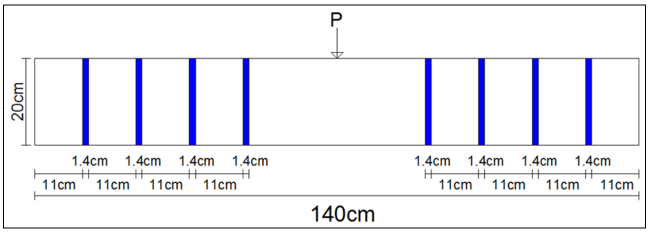

Fig 5: Schematic view of NSMV10 beam

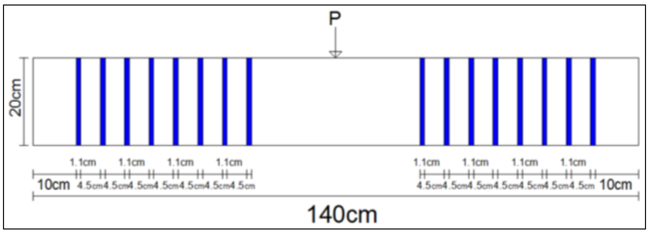

Fig 6: Schematic view of NSMV7 beam

4. Results

A 300-ton electric concrete breaker jack was used to load the reinforced concrete beam. This device is special for obtaining the compressive strength of cubic and cylindrical samples of concrete and was used to perform this test due to the lack of facilities. A steel beam was created from 20 mm thick steel sheets and reinforced with a stiffening sheet. Two steel beams with a diameter of 20 mm and a distance of 120 cm were welded and used as a support. First, the steel beam was placed on the moving part of the concrete breaker jack. Then, the reinforced concrete beam was placed on the rebars of the steel beam, and a rebar was placed above and in the middle of the opening of the reinforced concrete beam.

In this system, the rebar placed on the steel beam was considered as a support and the rebar placed on the middle of the opening of the reinforced concrete beam was considered as a concentrated load. In the lower center of the reinforced concrete beam, micro-gauge D1, to measure the displacement of the middle of the opening, and at the top of the reinforced concrete beam and in line with the support, micro-gauge D2 to measure The position of the support was changed (Gheitarani, N., *et al*., 2024a).

Fashion Break: In all the beams, shear failure was observed by a diagonal shear crack. These cracks gradually started from the concentrated load and spread towards the support area**.** The beams were broken when the GFRP rebars slipped and the adhesive coating was removed from the surface of the groove, creating diagonal cracks in the concrete, which indicates improper adhesion between the rebar and is concrete**.** As expected and the results of the existing tests also showed, this type of rupture was seen for shear reinforcement beams using the NSM method.

5. Findings

The final load of beams. NSMIL10 reinforced beam showed better performance than the other two beams. The weight of the NSMV10 beam was 6.87 tons, the NSMV7 beam was 7.94 tons, and the NSMIL10 beam was 11.29 tons. NSMIL10 beam compared to NSMV10 beam and NSMV7 beam increased by 64.3% and 42.2% in bearing capacity, respectively. The closer the intersection angle between the crack and the GFRP rebar is to 90 degrees, the better it is in preventing the crack from widening. In the NSMIL10 beam, the use of GFRP rebar at an angle of 60 degrees with the longitudinal axis of the beam caused the cutting of a diagonal shear crack at an angle of about 93 degrees.

In the NSMV10 beam, the angle between the rebar and the shear crack was about 62 degrees. This angle was recorded for the NSMV7 beam, about 65 degrees. It was found that the use of GFRP rebars with an angle of 60 degrees is more effective than 90 degrees. The bearing capacity of the NSMV7 beam increased by 15.6% compared to the NSMV10 beam. It was found that with the same amount of GFRP and the same installation angle, the use of rebar with a smaller diameter and a smaller distance has a greater effect on the final load of the reinforced beam. The number of GFRP bars that interrupt the shear crack increases the effect of shear reinforcement. Modeling of the tested NSMV7 beam was done with Abaqus finite element software. The way of crack propagation and the type of cracking in the modeled beam are very similar to the tested NSMV7 beam.

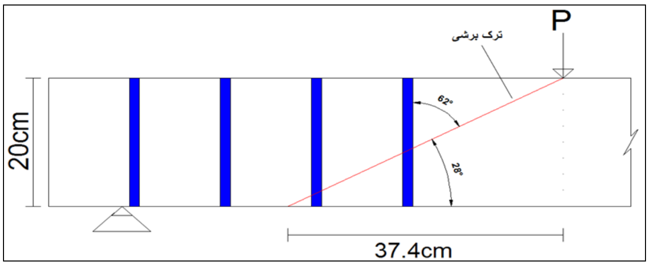

Fig 7: Schematic view of the angle between shear crack and GFRP rebar in NSMV10 beam

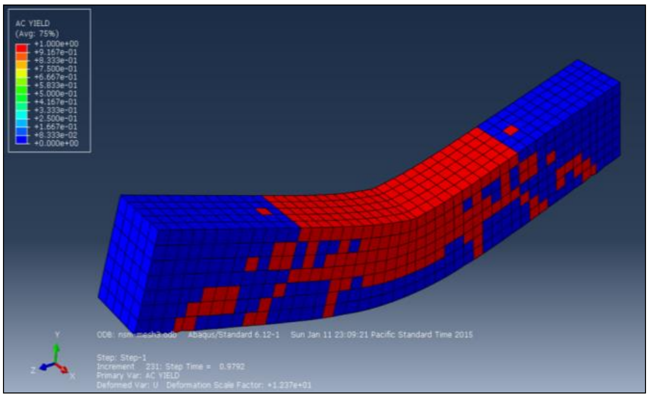

Fig 8: Comparison of the cracking behavior of the tested beam and the modeled beam of NSMV7

Reinforced concrete beams were tested in shear with different arrangements of GFRP rebars and by NSM method, to evaluate the optimal installation arrangement of GFRP rebars in the shear strengthening of reinforced concrete beams by embedding method near the surface. The amount of GFRP rebar used in beams is the same. The following results were obtained from this experiment:

In terms of failure mode, shear failure by diagonal shear crack was observed in all beams. These cracks gradually started from the concentrated load and spread towards the support area. The beams were broken when the GFRP rebars slipped and the adhesive coating was removed from the surface of the groove, creating diagonal cracks in the concrete, which indicates the improper adhesion between the rebar and the concrete. This type of breakage is common for NSM shear reinforcement beams. In terms of ultimate bearing capacity, the NSMIL10 reinforced beam showed better performance than the other two beams. NSMIL10 beam compared to NSMV10 beam and NSMV7 beam increased 64.3% and 42.2% respectively in final bearing capacity.

The closer the intersection angle between the crack and the GFRP rebar is to 90 degrees, the better it is in preventing the crack from widening. In the NSMIL10 beam, the use of GFRP rebar at an angle of 60 degrees with the longitudinal axis of the beam caused the cutting of a diagonal shear crack at an angle of about 93 degrees. In the NSMV10 beam, the angle between the rebar and the shear crack was about 62 degrees. This angle was recorded for the NSMV7 beam, about 65 degrees. It was found that with the same amount of GFRP and the same installation distance, the arrangement of GFRP bars with an angle of 60 degrees is more effective than 90 degrees.

The bearing capacity of the NSMV7 beam increased by 15.6% compared to the NSMV10 beam. It was found that with the same amount of GFRP and the same installation angle, the use of rebar with a smaller diameter and a smaller distance has a greater effect on the final load of the reinforced beam. The number of GFRP bars that interrupt the shear crack increases the effect of shear reinforcement. Modeling of the tested NSMV7 beam was done with Abaqus finite element software. Comparing the modeled and tested beams of NSMV7 shows that the way of crack propagation and the type of cracking in the modeled beam is very similar to the tested beam of NSMV7.

6. Conclusion

The results obtained from modeling, and conducting experiments; are the same and confirm each other. Next, numerical modeling results and test results will be given.

The results of the tests showed that the NSMIL10 reinforced beam has a better performance than the other two beams. Compared to the NSMV10 beam and NSMV7 beam, the NSMIL10 beam increased by 64.3% and 42.2% in bearing capacity, respectively. By comparing NSMIL10 and NSMV10 beams, it was found that with the same amount of GFRP and the same installation distance, the use of GFRP rebars with an angle of 60 degrees is more effective than 90 degrees.

The bearing capacity of the NSMV7 beam increased by 15.6% compared to the NSMV10 beam. By comparing NSMV7 and NSMV10 beams, it was found that with the same amount of GFRP and the same installation angle, the use of rebar with a smaller diameter and with a shorter distance has a greater effect on the final load capacity of the reinforced beam. In all the beams, shear failure was observed by a diagonal shear crack. The beams were broken by the sliding of the GFRP rebars and the removal of the adhesive coating from the surface of the groove, creating diagonal cracks in the concrete. This type of breakage is common for NSM shear reinforcement beams.

It is better to choose the distance between the GFRP bars in such a way that it is not difficult to implement. Modeling of the tested NSMV7 beam was also done with Abaqus finite element software. Comparing the modeled and tested beams of NSMV7 showed that the way of crack propagation and the type of cracking in the modeled beam is very similar to the tested beam of NSMV7. Modeling results showed that in the shear strengthening of reinforced concrete beam by NSM method with equal number and same installation distance of GFRP rods, the arrangement of rods with an angle of 45 degrees has the greatest effect compared to the angles of 60 and 90 degrees, and the arrangement of GFRP rebars with an angle of 60 degrees is more effective than 90 degrees.

Using modeling results, it was shown that in shear strengthening of reinforced concrete beam by NSM method with the same installation angle of GFRP rod, using a rod with smaller dimensions and less distance has a greater effect on the efficiency of the reinforced beam Compared to Beam1 control beam; Beam 7, which was shear reinforced by installing 32 GFRP rods with a distance of 45 mm and an installation angle of 45 degrees; about 44.86% has reduced the displacement of the middle of the beam span, which is the highest recorded strengthening percentage.

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