Diyala Journal of Engineering Sciences

Journal homepage: https://en.enginmag.uodiyala.edu.iq/

ISSN: 1999-8716 (Print); 2616-6909 (Online)

# Replacing Traditional Stirrups by Shear Steel Plate in High Performance Concrete Beams under Monotonic and Repeated Loads

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**ARTICLE INFO**

***Article history:***
Received 21 July 2020
Accepted 22 August 2020

***Keywords:***

Longitudinal shear steel plates; High performance concrete; Normal stirrups; steel fiber; Repeated load.

**ABSTRACT**

High performance concrete beam subjected to repeated loads is different from than the one subjected to static loads. Due to loading and unloading process crushing was caused by repeated loads in some part of concrete. Behavior of concrete under static loads was influenced by adding steel fibers, which amended many properties especially concrete tensile strength. These improvements are studied in this research under them effect of repeated loads, by testing simply supported high performance concrete fibrous reinforced beams with dimensions (1400x150 x 300) mm and percentages of steel fibers (0.5%) its design according to ACI544.4R-8[1]. The references is reinforced with normal stirrups while the other reinforced with different longitudinal shear steel plate. Repeated and static loads were applied to the beams through two points and for many cycles up to failure. All the results show low in ultimate strength under repeated load and increase in number and width of cracks. The results present that ductility under repeated load was less than under static load and the deflection under repeated load was higher than deflection under static load.

## 1. Introduction

High performance concrete (HPC) is defined as that kind of concrete which give the best performance and suitable result which cannot be carried out by normal concrete. HPC components are composed of essentially the same materials as conventional concrete mixtures, but the ratio are designed, or engineered, to supply the strength and traditional needed for the structural and environmental requirements of the project [2]. HPC is often made with the use of chemical and mineral admixtures such us superplasticizers, fly ash, ground granulated blast furnace slag, silica fume and steel fiber to produce a composite mainly characterized by its low porosity and fine pore structure. These, in turn, improve the resistance of concrete to the penetration of harmful substances such as chloride and sulphate, carbon dioxide, water and oxygen, and hence it provides high strength stiffness, thermal resistance ductility, and durability performance [3,4]. The addition of steel fibers also increases tensile strength, flexural strength, impact strength and toughness. The improved in toughness by fibers is useful in preventing sudden and explosive failure under static loading and in absorption of energy under dynamic loading (Ramadoss and Nagamani, 2008). [5]. In this research, Due to fast development of manufacturing for Computer numerical control machine CNC and some difficulties in stirrups stand with high cost and time entailed, some efforts have been made to discover new techniques is adopted for shear reinforcement depend on using the elongated

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DOI: 10.24237/djes.2020.13312

steel plate as shear reinforcement instead of normal stirrups (Ibrahim, et al., 2016). [6]. Large applications in structural engineering, like pile caps, foundations, bridge girders, and offshore structures, as well as transfer girders in tall buildings were subject to repeated load. The total number of load cycles may be as low as a few cycles to as high as several million cycles during the service life of beams (Teng, et al., 2000) [7] [8]. The exposure to repeated loading for many structure such like machine vibration, sea waves, wind action and automobile traffic results in a regular lowering in the stiffness of the structure, which may finally lead to fatigue failure [9] [10].

## 2. Experimental program

The experimental program includes testing six simply supported high performance concrete beams. All beams have the same dimensions and flexural reinforcement. They have an overall length of 1400 mm, a width of 150 mm and a height of 300 mm as shown in Figure (1).

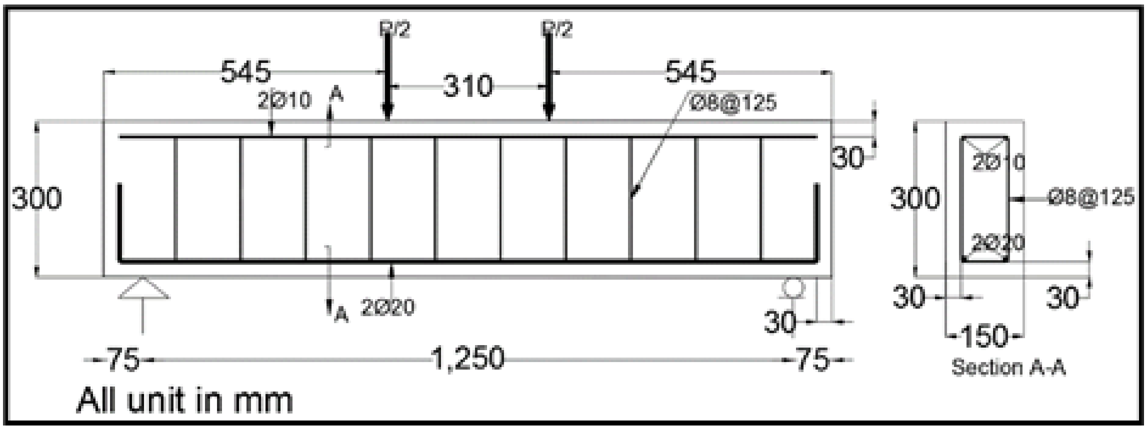


**Fig. 1.** Reinforcement details of reference beam

## 3. Materials

Ordinary Portland cement (type I) of Tasluja Factory (Iraq) is used in the present study, Al-Ukhaider natural sand is used in concrete mix, crushed gravel of maximum size 10 mm brought from Al-Ukhaider, straight steel fibers with 15 mm long and 0.2 mm diameter, (aspect ratio, l/d = 75), the density of the steel fibers is7800 kg/m3, and the ultimate tensile strength for fibers are 2000 MP. Total the volume fraction of 0.5% of the total volume of the mix in order to facilitating the fastening of concrete with steel plate and to get HPC, super plasticizer (High Water Reducing Agent – HWRA ), drinking water was used for mixing and curing all concrete mixes Deformed, Steel bars as shown in Table (1) and steel plate and reinforcement were used instead of shear reinforced with detailes and information as shown in Figure (2) and Table (1) to Table (3).

**Table 1** Yield and ultimate stresses and elongations of steel bars

| Nominal bar diameter(mm) | Bar cross area(mm2) | Yield stress (MPa) | Ultimate stress (MPa) |
|---|---|---|---|
| 8 | 50.26 | 390 | 520 |
| 10 | 78.54 | 360 | 485 |
| 20 | 314.15 | 589 | 658 |

**Table 2** Yield and ultimate tensile strengths and elongations of the steel plates

| Thickness of tested steel plate (mm) | Average of yield tensile strength (MPa) | Average of ultimate tensile strength (MPa) | % Elongation at ultimate stress |
|---|---|---|---|
| 3 | 320 | 426 | 20.5 |

**Fig. 2.** Steel plate used

## 4. Concrete Mix Design

The High-performance concrete is mixed by using a horizontal rotary mixer of 0.1m^3 capacity available in the material construction laboratory. Table (3) illustrates the amount of material used in the mix with compressive strength equal to 85 MPa. The compressive strength test of concrete fcu was carried out according to (B.S.1881: Part 116: 1983) [11] using standard cube (100*100*100) mm. They were tested under compression using a universal testing machine available in the Structural Laboratory of Engineering College of Diyala University at a loading rate of 0.3 kN/s using 2000 kN capacity as shown in Figure (3).

**Fig 3.** Concrete compressive strength test

**Table 3** Mix design

| **Materials** | **Cement (kg/m3)** | **Coarse aggregate (kg/m3)** | **Fine aggregate (kg/m3)** | **Steel fiber (kg/m3)** | **S P** | **Water (kg /m3)** |
|---|---|---|---|---|---|---|
| C85 | 628.6 | 911.43 | 571.43 | 39 | 20 | 137.14 |

## 5. Instrumentation and test procedure

All beams were tested using a hydraulic universal testing machine of 2000kN capacity under static and repeated loads up to ultimate load at the Structural Laboratory of the College of Engineering / Diyala University. Loading history for repeated load were illustrated in Figure (4).

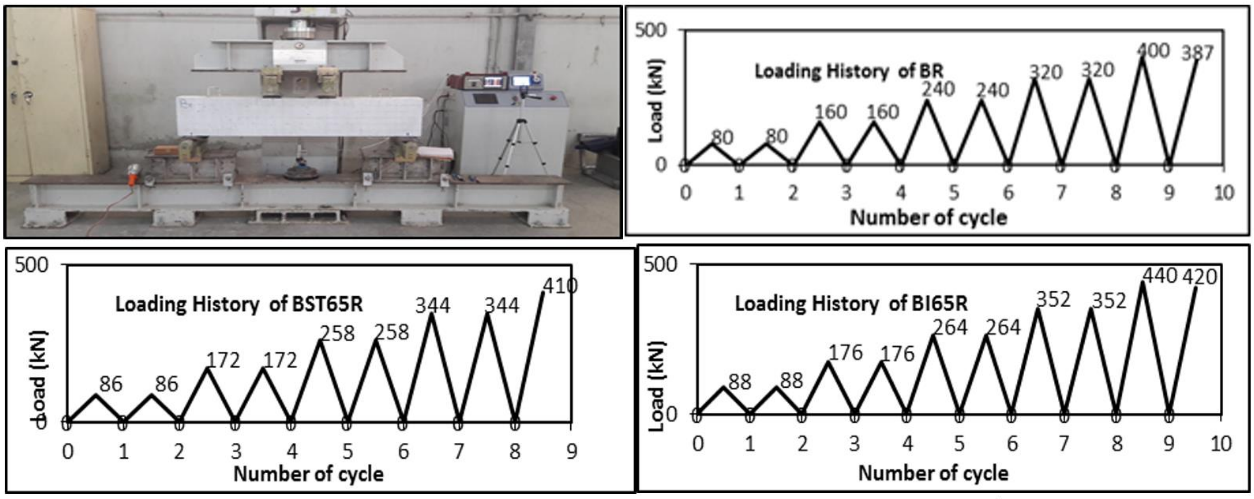


**Fig. 4.** Position of beams in the load-testing machine and loading history of beam under repeated load

## 6. Details of specimen

In this research, six high performance reinforced concrete beam specimens are tested. These beams are identical in length(L=1400mm) and cross section of (150mm x 300mm).

References (BM, BR) were reinforced with traditonal stirrups once under static and the other under repeated loads, other beams different in the shear reinforcement where (BPV65=steel plate contain vertical hole with 65mm spacing between it once under static and the other under repeated loads),BPI65= steel plate contain inclined holes with 65mm spacing between it once under static and the other under repeated loads) according to these variables, ultimate loads, load-deflection behavior, concrete compressive strain as well as crack patterns are different from each to other. Beams details are shown in Figure (5). The designation in detail are shown in Table (5) bellow.

**Fig. 5.** Details of steel plates used

**Table 5**. Detailing of designation way

| Letters | Designation |
|---|---|
| BM | Beam with stirrups @125 mm under monotonic load |
| BPV65M | Beam with steel plate contain vertical holes with 65 mm spacing between there under monotonic load |
| BPI65M | Beam with steel plate contain inclined holes with 65 mm spacing between there under monotonic load |
| BR | Beam with stirrups @125 mm under repeated load |
| BPV65R | Beam with steel plate contain vertical holes with 65 mm spacing between there under repeated load |
| BPI65R | Beam with steel plate contain inclined holes with 65 mm spacing between there under repeated load |

## 7. Discussion of results

A series of six high performance concrete beam have been tested in bending under static and various history load types. The amount of deflection at yield and ultimate loads, ultimate load and ductility were illustrated in Table (6). and Figure (6) and Figure (7). The load-deflection curves for the tested specimens show that the deflection at yield load in beams with shear steel plates (BPV65M, BPV65R) was lower than the reference beam (BM, BR) and higher in (BPI65R). It was shown that the deflection at the ultimate load in beams (BPV65M and BPI65M) was higher than the control beam (BM) also in beams (BPV65R, BPI65R) it was higher than the control beam for group 2. On the other hand, the ductility (Δu/Δy) in the beam (BPV65M and BPI65M) was higher the than control beam (BM) group1 its was also higher than the control beam group2 in the (BPV65R, BPI65R).

**Table 6**. Experimental Results

| Name of beams | Py (kN) | % diff. in Py | Δy (mm) | % diff. of Δy | pu (kN) | % diff. in pu | Δu (mm) | % diff. of Δu | Ductility | % diff. in ductility | Mode of failure |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Group1 | | | | | | | | | | | |
| BM | 352 | --- | 10.12 | --- | 402 | --- | 18.54 | --- | 1.83 | --- | Compression Flexural |
| BPV65M | 341 | -3.13 | 8 | -20.95 | 433 | 7.71 | 20.49 | 10.52 | 2.56 | 39.9 | Flexural |
| BPI65M | 380 | 7.95 | 9.32 | -7.91 | 443 | 10.2 | 26.49 | 42.88 | 2.84 | 55.2 | Compression Flexural |
| Group2 | | | | | | | | | | | |
| BR | 333 C10↑ | --- | 15.12 | --- | 387 | --- | 24.12 | --- | 1.6 | --- | Shear |
| BPV65R | 325 C9↑ | -2.4 | 9.54 | -36.9 | 410 | 5.94 | 24.3 | 0.75 | 2.55 | 59.38 | Compression Flexural |
| BPI65R | 360 C10↑ | 8.11 | 16.43 | 8.66 | 420 | 8.53 | 28.59 | 18.53 | 1.74 | 8.75 | Compression Flexural |

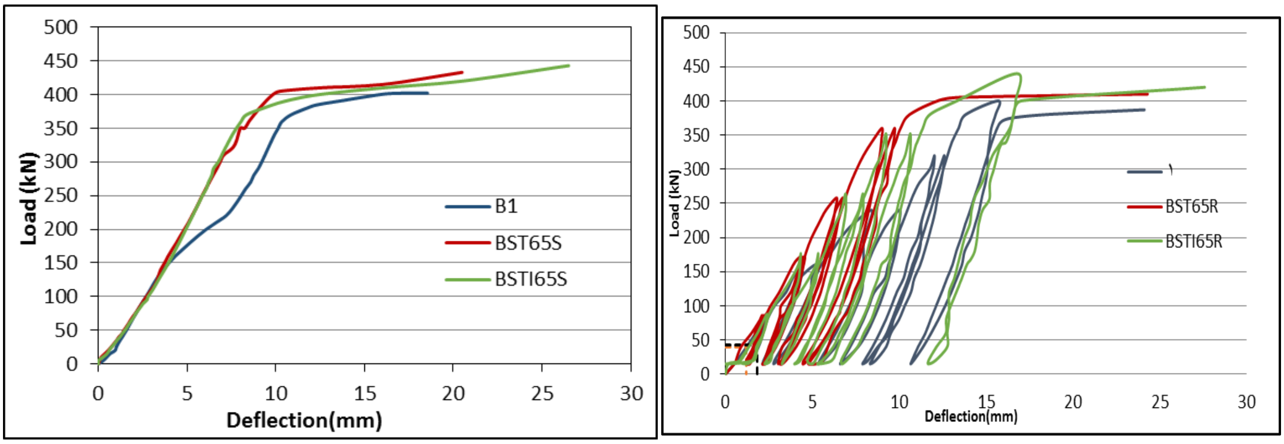


**Fig. 6.** Load –deflection curve under static and repeated load

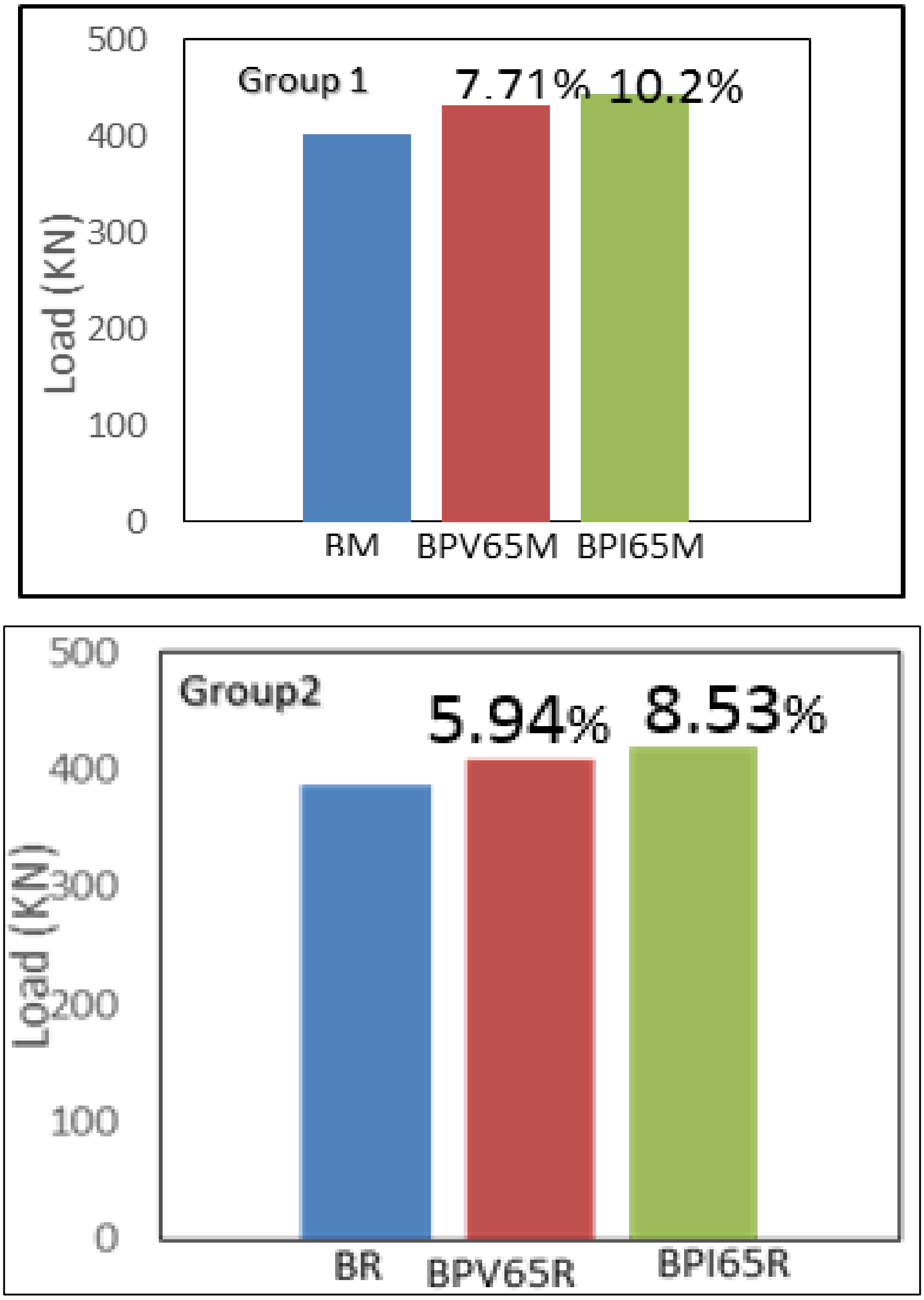


**Fig. 7.** Ultimate load capacity for specimens

## 8. Crack patterns and mode of failure

After every load addition the cracks and any probable failure marks HPC beam were checked. The first crack appeared in the mid-span. When the load was increased and after proceed of the first crack more cracks start to appear in both length and width all cracks continued persistent to develop. The cracks appear at supports and propagated towards the loads at large loads as shown in Figures (8) to Figure (13).

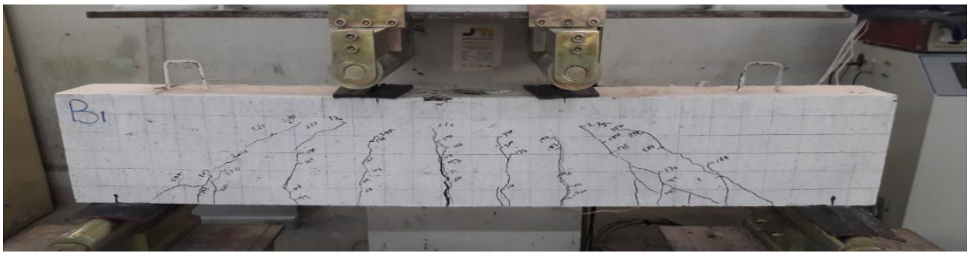


**Fig. 8.** Failure of beam BM

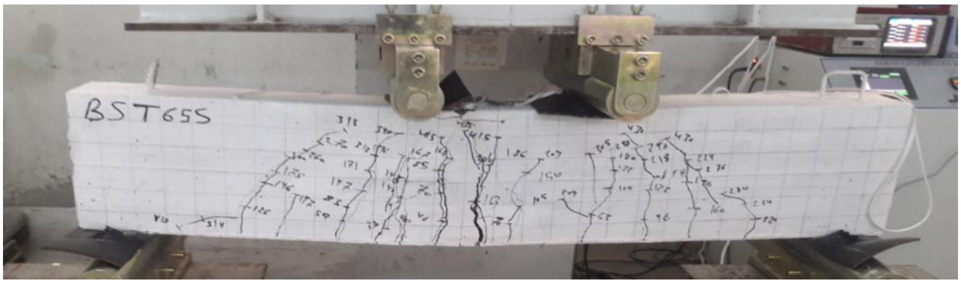


**Fig. 9.** Failure of beam BPV65M

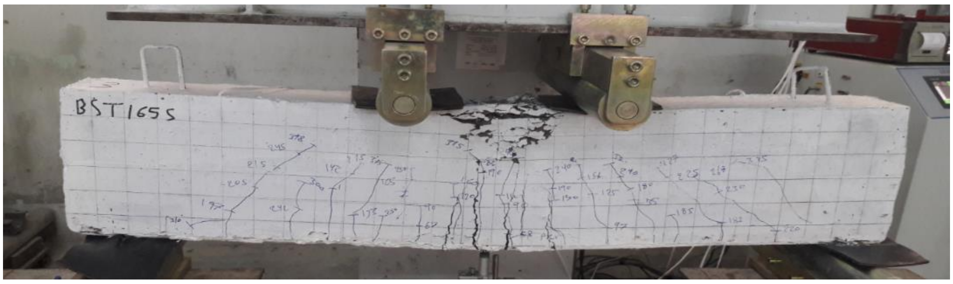


**Fig. 10.** Failure of beam BPI65M

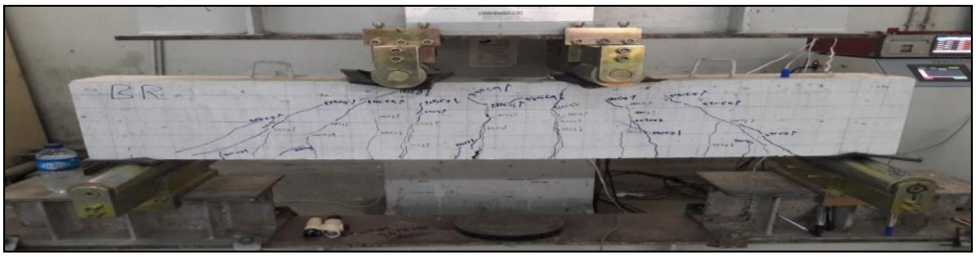


**Fig. 11.** Failure of beam BR

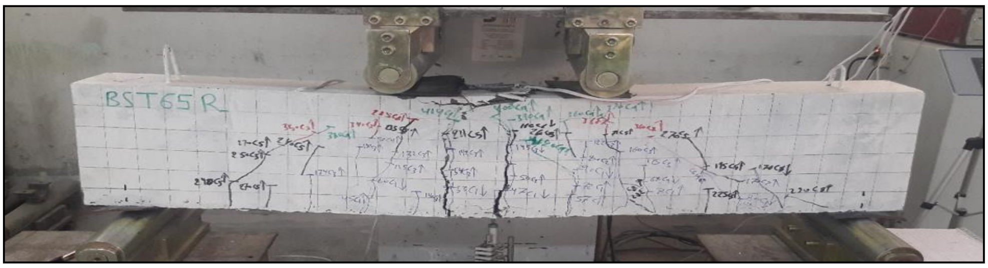


**Fig. 12.** Failure of beam BPV65R

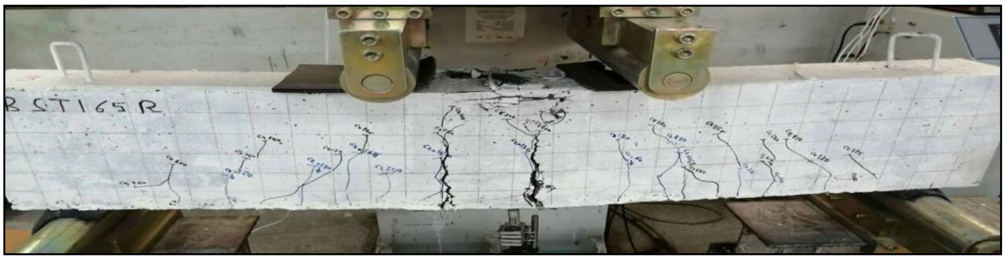

**Fig. 13.** Failure of beam BPI65R

## 9. Result and conclusion

The general behavior of the tested beam under static load was studied with varying some parameters, such as spacing between holes and its direction.

1- The result show that the longitudinal shear steel plates are a good alternative to use instead of normal stirrups whatever the case under static and repeated load.
2- Ultimate strength for all beams used steel plate was higher than the reference used stirrups.
3- The control beam (BR) having ultimate strength lower than the control beam reinforced with stirrups under static load by about (3.73%).

The longitudinal shear steel plates beams (BPV65R) contain vertical rectangular holes with 65mm spacing having ultimate strength lower than the same beam under static load by about (5.31%).

4- The longitudinal shear steel plates beams (BPI65R) contain inclined rectangular holes with 65mm spacing having ultimate strength lower than the same beam under static load by about (5.19%).
5- The control beam (BR) having ductility lower than the control beam reinforced with stirrups under static load by about (12.57%).
6- The longitudinal shear steel plates beams (BPV65R) contain vertical rectangular holes with 65mm spacing having lower ductility lower than the same beam under static load by about (0.39%).
7- The longitudinal shear steel plates beams (BPI65R) contain inclined rectangular holes with 65mm spacing having ductility lower than the same beam under static load by about (38.73%).
8- The control beam (BR) having higher deflection at ultimate load higher than the control beam reinforced with stirrups under static load by about (30.1%).
9- The longitudinal shear steel plates beams (BPV65R) contain vertical rectangular holes with 65mm spacing having higher deflection at ultimate load than the same beam under static load by about (18.59%).
10- The longitudinal shear steel plates beams (BPI65R) contain inclined rectangular holes with 65mm spacing having higher deflection at ultimate load than the same beam under static load by about (7.93%).

TBM (tunnel boring machine) is designed as plate elements and should be 9 m long and is designed as plate elements for the segmental tunnel liner. Table 2 describes the tunnel system parameters [12]. Portion is believed to be 1.5 m wide each part in the concrete lining used, and hence TBM advances 1.5 m at each tunnelling stage frequency. The concrete lining segments are formed by the application of structural elements with flexible linear behavior of the properties formed. Table 3 presents the material properties of lining elements.

## Acknowledgment

This work was supported by Diyala University, Civil Engineering Department, which is gratefully acknowledged.

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