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Bending Capacity of Precast Channel System (U-Ditch) with Corrugate Wall

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Abstract: ***The precast channel system (U-Ditch) is one of the innovations of precast concrete designated as a channel for drainage and irrigation systems. In Indonesia particularly, there have been many precast companies that produced U-Ditch. The precast channel system will carry a major load due to ground pressure from traffic load. Therefore, the precast channel wall must have sufficient bending capacity to resist the load without the structural damage. On the other hand, the addition of wall thickness will lead to the heavy construction product. Therefore, to minimize the wall thickness, the outer wall of the channel was reduced. To identify the bending capacity and the failure mode, the loading test of 500x500 U-ditch with a reduction of wall thickness (corrugate) was conducted and its results were compared with U-ditch without a reduction of wall thickness (normal). The specimens were tested based on Japan Industrial Standard (JIS). The test results showed that the reduction in thickness of U-Ditch reduced 10% of normal U-ditch weight. However, the bending capacity per unit weight decreased. The future work of this study was to strengthen the corrugate wall by using fiber reinforced plastic (FRP) in order to improve the bending capacity of this product.***

Keywords: **U-ditch, Precast Concrete, Bending Capacity, Corrugate.**

I. BACKGROUND

The use of precast construction system provides several advantages, such as a good structure quality, faster construction work, and longer durability.

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Precise construction has also evolved to the construction of drainage channels (U-Ditch). In developed countries such as Japan almost all drainage systems used precast system. In Indonesia, especially in Makassar City, precast U-ditch has also started to develop and is used in some drainage infrastructure. However, the local products are not uniform, both dimensions and quality because there is no standard system of design and construction processes. **Figures 1** and **2** respectively show 800x800 mm U-Ditch product manufactured in Indonesia and Japan.

In general, the thicker the wall of the channel will be the higher the capacity of the channel structure in carrying the load of soil pressure and vehicle loads. The production of precast system especially the channel is still not equipped with standard and complete standard, so there are various variations both geometry and system structure. In some developed countries such as Japan already have standards related to precast structures including channels. This is as a standard reference so as to obtain a quality channel system with optimum structure thickness. **Figure 2** shows an example of a pre-cast production channel of 800 × 800 mm which is produced by Japanese company. Preprinted concrete well produced using standard will result in a well-resilient construction system [1]. Some precast elements have been developed for important structural elements to ensure their durability as for connection systems [2].

This paper presented the results of the innovation of precast channels by reducing the weight of the structure while maintaining its strength. The channel structure was designed based on Japan Industrial Standard (JIS). The

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a. U-Ditch in Indonesia b. Construction site

Fig 1.U-Ditch Product in Indonesia

a. U-Ditch in Japan b. Construction site

Fig 2.U-Ditch Product in Japan

standards used in the production of precast systems include the various standards of JSCE 2012 [3], JIS A 5345 [4], JIS A 5362 [5], JIS A 5363 [6], JIS A 5365 [7]. By using such standards as references, the precast channel system in this study was done by reducing the thickness of the channel wall.

II. INNOVATION PRODUCTS OF PRECAST CHANNEL SYSTEM (U-DITCH)

In a study conducted by Djamaluddin et al [8, 9], a review of the potential of U-Ditch precast product with Japanese standards was carried out by using local materials and construction methods that could be applied in Indonesia. The study process was done by comparative study on the geometry, the reinforcement system and the moment capacity of each product. The results indicated that U-ditch local products have many limitations, such as: (1) the thickness is greater than Japanese product, (2) the weight is heavier than Japanese product, (3) Has a non-slick concrete surface such as a Japanese product, (4) the reinforcement is more focused on the symmetrical side of the cross section, and (5) the strength is lower and less ductile. On the other hand, U-ditch Japanese products have many advantages compared to the local products, such as: (1) the thickness is thinner, (2) Weigh is lighter, (3) the reinforcement configuration is less focused on the symmetrical side of the cross section, and (4) The bending capacity is much higher and ductile to resist the applied load.

In order to improve the lack of U-ditch local product, Djamaluddin et al developed an innovation product by taking all the advantages possessed by the U-Ditch Japanese product. The loading design was based on Japan Industrial Standard (JIS), not the Indonesian Standard. **Figures 3(a)** and **(b)** compare the Indonesian and Japanese standard for loading design, respectively. According to the Indonesian standard, the pressure loads which are obtained from the soil pressure and the vehicle load are separated. On the other hand, in Japanese standard, these two loads are combined. The vehicle load (Q) in Japanese standard is about 49.1 kN. This results in 3.71 kN.m bending capacity. Further, it will be used to design the innovation products as shown in **Fig. 4**.

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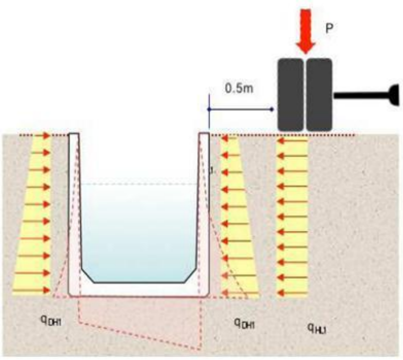


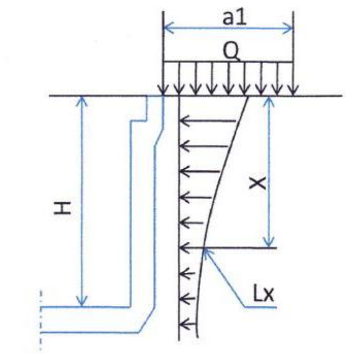
LATERAL LOAD

- Soil pressure
- Vehicle load
- Hydrostatic pressure

LOAD DISTANCE

- Minimum load distance is 0.5m
- If the distance<0.5m, strengthening and special design are required.

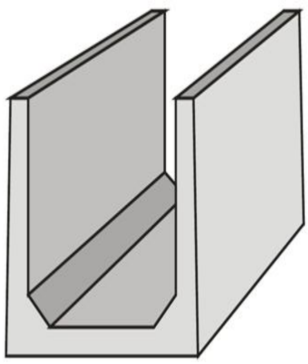
a. Loading design in Indonesia



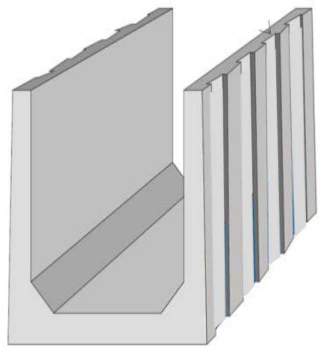
Lx : Load strength with load (kN/m^2)
Ka : Coefficient of active pressure load Coulomb
Q : Wheel load (49,1 kN)
I : Shock Factor (0,1)
Li : Length (2,0 m)
Ai : Soil width (0.5m)
X : Soil depth (m)
H : Height of channel

b. Loading design in Japan

Fig 3. Comparison of Loading Design in Indonesia and Japan



a. U-Ditch Normal



b. U-Ditch Corrugate

Fig 4. Innovation of Precast Channel System

There are two innovation products developed in this study which were the U-Ditch product without the reduction of wall thickness (normal) and the U-Ditch product with the reduction of wall thickness (*corrugate*). **Figures 4(a)** and **(b)** shows these two products respectively. The idea of making U-Ditch precast with corrugate walls is to reduce the weight of the channel structure. By using corrugated wall, the weight of channel structure type 500x500 mm can be reduced to 10%. The thickness reduction is carried out as wide as 100 mm along the channel wall height in each area between the main reinforcement so that it resembles a corrugate wall. With this thickness reduction, the concrete cover on each of the main reinforcements is still in accordance with the minimal concrete cover of 20 mm as required by JIS [7,8].

III. SPECIMENS AND TEST SET-UP

A. Specimens

Two types of U-Ditch were tested in this study. The first type was the normal U-ditch without the reduction of wall thickness (Type P) while the second type was U-ditch with the reduction of wall thickness (Type C). The dimensions of these products were 500 x 500 x 1000 mm. **Figures 5**and**6** show the dimensions of Type P and C, respectively.

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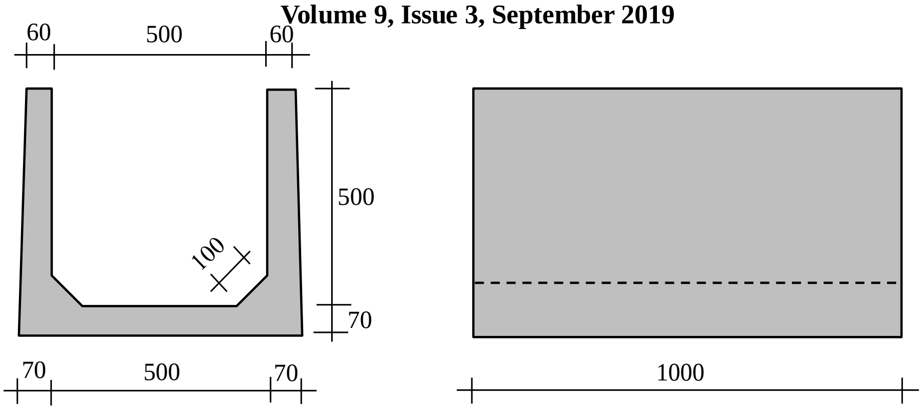

Fig 5. Dimension of Type P (Normal)

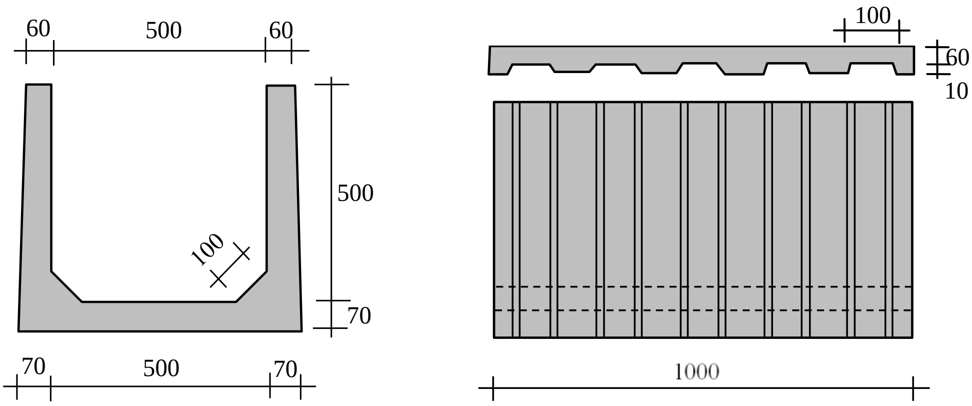

Fig 6. Dimension of Type C (*Corrugate*)

Minimum wall thickness was about 60 mm at the top of the channel wall. The thickness gradually reduces to the hook part of the wall with a thickness of 70 mm. This was because the soil pressure and vehicle loads also gradually increase from the top to the bottom of channels. The thickness of the channel bottom is uniform with a thickness of 70 mm. For Type C (corrugate), maximum channel thickness was the same as type P but there is a reduction of local wall thickness in each spacing between main reinforcements with a thickness of 20 mm and a width of about 100 mm. This configuration formed corrugate wall.

Figure 7 shows the arrangement of reinforcement. The diameter of main reinforcement was 10 mm with spacing of 190 mm. Meanwhile, the diameter of shrinkage reinforcement was 8 mm with spacing of 200 mm. On the hook section, 8 mm diameter reinforcement was used for compression reinforcement. All the reinforcements were assembled by welding connection.

B. Materials

The concrete was designed with the average 28-day cylinder compressive strength of 25 MPa. The concrete compressive strength was measured on 100x200 mm concrete cylinder. The 10 mm deformed rebars and 8 mm plain rebars were tested in tensile and the measured yield strength was 400 and 400MPa, respectively.

C. Fabrication Procedures

Figure 8 shows several procedures in U-Ditch fabrications. The test specimen's were casted by using steel formwork to produce a more precise product compared to the wooden formwork. The casting of the specimen was carried out in reverse side, where the bottom side was positioned on the top. This was to facilitate the casting process and also to avoid the segregation of concrete on the bottom surface of the channel. The filling of the concrete started on the channel wall and was done gradually as shown in **Fig. 8 (a)**. Furthermore, the compaction was done manually by using steel bars. After casting, proceed with compaction of specimens by using a vibrator for approximately 20 seconds (**Fig. 8 (b)**).

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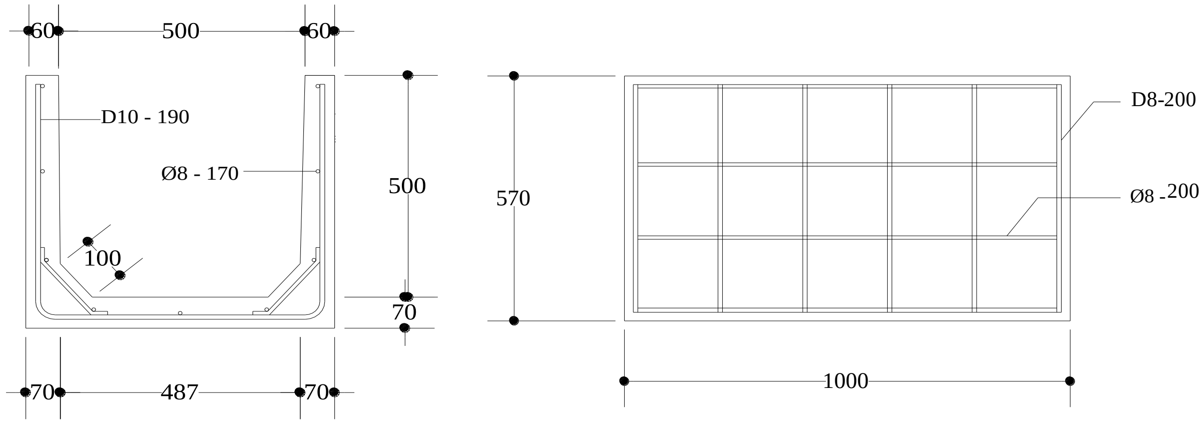

Fig 7. Detail of reinforcement

a. Casting channel wall

b. Compaction using vibrator

c. Curing

Fig 8. Fabrication procedures

The curing of specimens was done manually by using a wet sack for approximately 3 days as shown in **Fig. 8 (c)**. After sufficient curing time, the formwork was de-molded. Prior to loading test, the weight of each specimen was measured. The weight of the Type P (normal)was 252 kg and the Type C (corrugate) was 229 kg. Due to reduction of wall thickness, the weight of Type C decreased by 10% compared to Type P.

D. Instrumentations and loading methods

Figure 9 shows the loading setup. It was carried out based on the testing method performed in Japan (JIS) because SNI has not set specific test standards. The test was carried out by loading the channel wall from both sides with a pull rod connected to the load cell. The applied load was monitored through the load cells placed on each end of the pull rod. LVDT (Linear Variable Data Transducer) was placed near the load cell to measure the deflection that occurs on channel wall. Strain gauge was attached on the concrete surface near the hook to measure the concrete strain at that location. Moreover, several strain gauges were also attached on the reinforcements. The locations of LVDT and strain gauges are shown in **Fig. 9**.

Figure 10 shows the method for applying the load. The load is given manually by turning 90 degree of the nut on the ends of the pull rod. Hence, it will clamp the sides of the inner wall of the channel to produce the pressure load. The loading was limited until the deflection of the wall about 15 mm because the crack width was large and the load from the load cell was not increased.

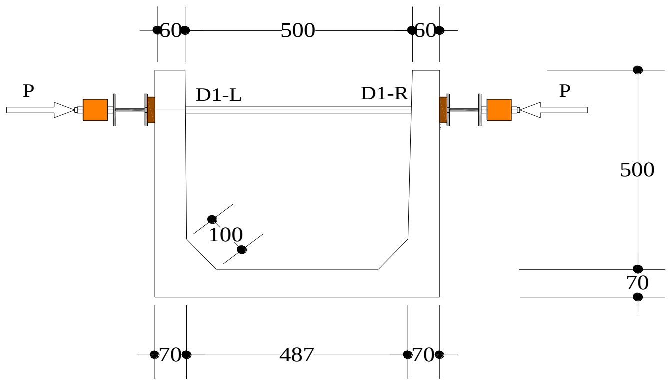

Fig 9.Loading Setup

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Fig 10.Application of load

IV. RESULTS AND DISCUSSIONS

A. Ultimate Capacity

Table 1.Experimental results

Specimen	Weight (kg)	First cracking load, P_{cr} (kN)	Ultimate load P_{max}at 15 mm displacement(kN)	M_{max} (kN.m)	
				by M'	By weight (t)
Type P	252	10.19	25.57	8.98	35.52
Type C	229	6.26	19.73	6.90	30.15

Table 1 shows the experimental results for all specimens. All the data presented in this table are the measured at the displacement of 15 mm. For Type P (normal), the first crack occurred when the load of 10.19 kN and the ultimate load of 25.57 kN. Meanwhile, for Type C (Corrugate), the first crack occurred at the load of 6.26 kN and the ultimate load of 19.73 kN. These indicated that compared to Type P, the first cracking load and the ultimate load for Type C decreased by 38.56% and 22.84%, respectively (**Fig. 11**). This was because the stiffness of the specimens decreased due to the reduction of the wall thickness. To solve this problem, the ultimate capacity of Type C can be increased by several ways, such as by strengthening the corrugate wall with Fiber Reinforced Polymer (FRP).

B. Ratio of Moment Capacity to Weight

The ratio of the moment capacity to the weight of the structure is shown in **Table 1**. The measurements of the weight of each specimen were performed before the loading test. In this table, it can be seen that the moment capacity of Type P and Type C was8.98 kN.m and 6.90 kN.m, respectively. If the moment capacity was divided by weight to show the moment capacity per unit of precast channel weight, Type P had the moment capacity per weight of 35.52 kN.m/ton and Type C had the moment capacity per weight of 30.15 kN.m/ton. This indicated that compared to the Type P (normal), there is a decrease in the ratio of the moment capacity to the weight of the structure by 15.11% in Type C (corrugate) as shown in **Fig. 12**.

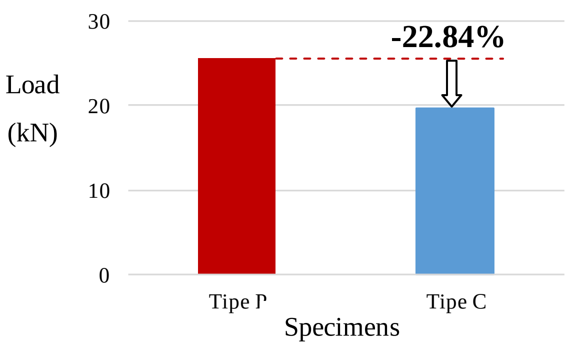

Fig 11.Ultimate load

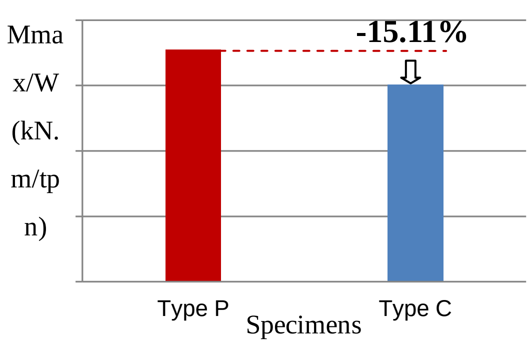

Fig 12. Ratio of moment capacity to weight

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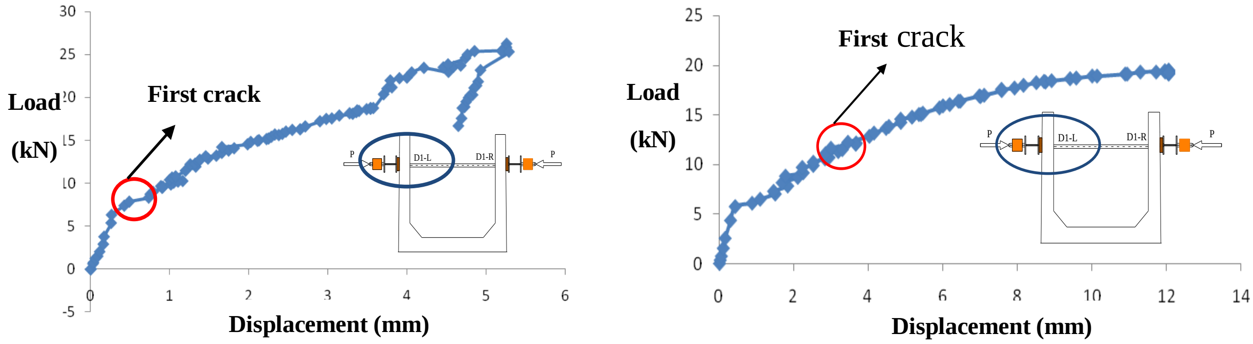

a. Type P (Normal)

b. Type C (*Corrugate*)

Fig 13. Load-displacement relationship

1. *Load-displacement Relationship*

Figure 13 shows the relationship between the applied load and displacement at the loading point. The load and deflection relationship shows the response of the structure due to the increasing of load. Basically, at the initial load, the behavior of load-deflection relationship follows the behavior of reinforced concrete structure where the compressive stress will be borne by the concrete and the tensile stress will be restrained by the reinforcement and the concrete. After cracking of concrete in the tension zone, the tensile stress is only restrained by the reinforcement (James K. Wight (2011)). The cracks occur when the tensile stress that occurs in the concrete is greater than the tensile stress of the concrete. The crack will cause a decrease in the stiffness marked by the change in the direction of the load deflection curve. In **Fig. 13** it can be observed that the first crack in Type P occurred at the load of 10.19 KN with the deflection of 3 mm. For Type C, the first crack occurred at the load of 6.26 KN with the deflection of 0.5 mm. The subsequent increase in loading was still accompanied by the addition of deformation until there is a widening crack and the formation of new cracks. It should be noted that in this study the loading was limited to the deformation at about 15 mm. The load at the deflection of about 15 mm for the Type P and C was 25.6 KN and 19.7 KN, respectively.

2. *Load-Strain Relationship*

The load and strain relationship in this study was observed through the measured strain in concrete and steel bars from the initial load to the ultimate load. The relationship between the load and strain in concrete and steel bars are shown in **Figs. 14** and **15**, respectively.

Figures 14 (a) and **(b)** show the relationship between the load and strain at concrete. The concrete gauge was attached on the area around the hook of the channel wall. In the Type P, it appears that the strain-load behavior is elastic until collapse. Initial cracks occurred when the concrete strain value was 318. Then with increasing load, the specimen reached the ultimate load at the strain of 1120. Meanwhile, on the Type C, it appears that the load-strain behavior is also elastic until collapse. Initial cracks occurred when the concrete strain value was 307.Then as the load increased; the specimen reached the ultimate load at the concrete strain of 650.These results indicated that the ultimate strain of concrete in Type P was higher than Type C.

Figure 15 shows the relationship between the load and strain at steel bars. The steel gauge was attached at the main reinforcement, exactly at the hook part. For Type P, the crack occurred at 318 then with the increasing load, the measured strain increased to 1880. Meanwhile, for Type C, the crack occurred at 737 then with the increasing load, the measured strain increased to 1450.

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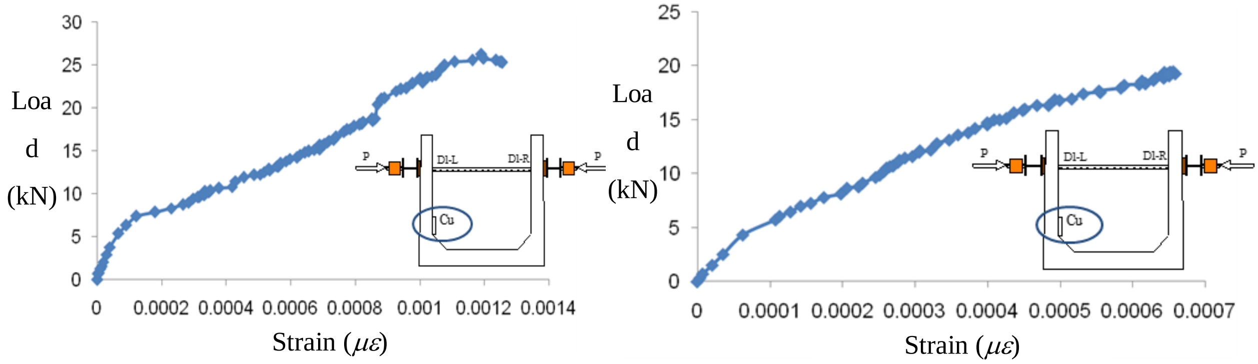
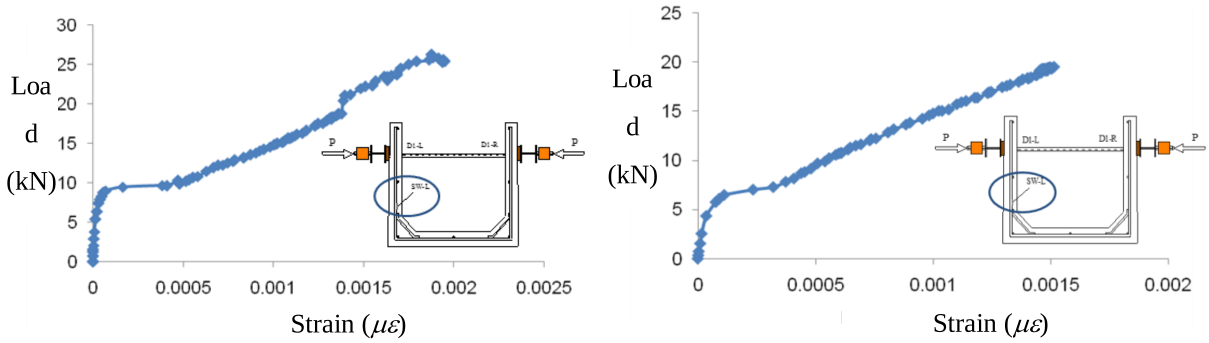


a. **Type P (Normal)** b. **Type C (Corrugate)**

Fig 14.Load-strain at concrete



a. **Type P (Normal)** b. **Type C (Corrugate)**

Fig 15.Load-strain at steel bars

C. Crack pattern and failure mode

In general, the crack pattern for both Type P and Type C was the flexural cracks. The first crack was observed around the hook part of the channel as shown in **Fig. 16**. The failure occurred due to the propagation of the cracks.

Fig 16.Crack pattern

V. CONCLUSION

The investigation on bending capacity of precast channel system (U-Ditch) with corrugate wall has been presented. The results are summarized as follows:

a. The weight reduction in U-Ditch Corrugate by 10% affected 22.1% reduction in bending capacity.

b. The weight reduction in U-Ditch Corrugate also resulted in a reduction in the ratio of flexural capacity by weight around 15.11%.

c. An innovation was required to improve the bending capacity of U-Ditch Corrugate such as by strengthening using FRP (Fiber Reinforced Polymer).

d. The U-Ditch precast channel failed in flexure due to the large displacement.

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