Finite element analysis on flexural behavior of non-prismatic longitudinal section reinforced concrete deep beam

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Abstract. Increasing of building constructions demand affects the innovation for developing structural elements, especially in the beam element known as deep beams. The deep beam is a popular beam with an adequate ratio of a/d < 1.0. Therefore, Compared to the standard beam, the strength of the deep beam shows better. It also can be applied to various construction. Based on observations in the field, the length of the cross-section of the deep beam varies significantly, starting from the prismatic and non-prismatic shapes. Therefore, this research has conducted to determine the effect of non prismatic longitudinal section variations on the RC deep beam behavior using finite element method. The simulation model analyzed consists of one prismatic longitudinal section and two types of the non-prismatic longitudinal section. The result shows that the non-prismatic longitudinal of the deep beam gives effects on slightly decreasing flexural load, ductility and failure mode. The failure modes shown in models show the same characteristics, which are both experiencing shear failure.

1. Introduction
Increasing in construction demand is linearly depend on the expanding challenges faced in the field. For example, the construction of high rise buildings, bridges and offshore structural element needs beam structural element which has large load capacity. In addition, the application of reinforced concretes beam are inadequate. Therefore, several researchers have previously developed beams into deep beams capable of supporting transverse loads to meet structural building demand [1-4]. Commonly, reinforced concrete consist of 3 types according to the aspect of shear span to effective depth ratio (a/d), i.e. deep beam (a/d < 1) moderately deep beam (1 < a/d <2.5); ordinary shallow beam (a/d > 2.5) [1-3]. Within the deep beam because the high proportion of the depth to length the strain is typically not distributed linearly throughout the whole area. Therefore, planning of the deep beam needs more attention of shear [3-7]. In moderate deep beam reinforced concrete, shear-flexural failure usually occurs due to flexural strength equal to the shear strength [8].

Parameter which affect on the strength behavior of the deep beam is the size effect [9]. Kamaran et al. [10] have research about the effect of shear capacity and a/d ratio of deep beam. The result shows
that the compressive strength and the shear span to depth ratio have more impact on the shear stress. Increasing in size that occurs in a deep beam will cause flexural cracks that dominate and the web reinforcement distribution plays an important role in determining the size effect on deep beams [11]. Many studies have discussed about the effect of cross section [12], but few studies have been conducted about the effect longitudinal section of beam. Moreover, the reality occurred in field construction needs the aesthetic value. It also affects the rise of the non-prismatic section. Therefore, in this research has studied about the effect of non-prismatic longitudinal section on deep beam by observed its flexural behavior such as load displacement relationship, ductility and failure mode. Not only that, the comparison between prismatic and prismatic longitudinal section also has carried out in this research.

2. Methodology

2.1. Geometric model
In this research, there are two types of deep beam cross-section studied such as T-deep beam and I-deep beam. Each beam cross-sections consist of three variants, one of prismatic longitudinal section and two of the non-prismatic longitudinal section. In order to make flexural reinforcement, the rebar diameter of 16 mm was used as flexural reinforcement in the deep beam model. Besides, the rebar diameter of 12 mm is installed at each 150 mm as shear reinforcement. The detailing reinforcement and section of deep beam can be illustrated in Figures 1 and 2.

![Figure 1. Variation of longitudinal section of T-deep beam.](image-url)
2.2. Material properties
According to the compressive test of concrete, the elastic parameter and plastic parameter need to be input on the numerical software. Concrete modulus elasticity of 24870 MPa and poison ratio of 0.15 as an elastic parameter. Concrete damaged plasticity was chosen for idealizing plastic behavior of concrete shown in Table 1. In addition, Compressive stress-strain, tensile stress-strain and damaged parameter should be input to represent the plastic behavior of concrete material. It can be shown in Figure 3(a). that three type of yield strength in steel material were used for assign in flexural reinforcement and shear reinforcement. There are two conditions of material which need to be input in ABAQUS such as the elastic and plastic condition. In elastic condition, Steel modulus elasticity of 200000 MPa and poison ratio 0.3 are inputted in the software while tensile testing result like stress-strain relationship inelastic can represent the plastic condition. Concrete and steel properties can be shown in the Figure 3(b).

2.3. Finite element analysis
Abaqus software was used for conduct finite element analysis of deep beam models. 3D solid extrusion represents the concrete deep beam modelling while rebars idealize in wire planar that commonly used by the previous researcher [13]. An eight-node linear brick element (C3D8R) idealized for concrete type element and type element which had used for transversal and longitudinal
rebar is truss T3D2 which can be seen in the Figure 4. The pinned joint was applied in the support as a boundary condition which can be seen in the Figure 2. General static in nonlinear condition using full newton selected as a numerical method. The interaction between concrete and rebar is embedded interaction.

![Stress-strain relationship of concrete and steel](image)

**Figure 3.** Stress and strain relationship of (a) concrete and (b) steel [14, 15].

| Dilatation angle | Eccentricity | $F_{0d}/f_{c0}$ | K | Viscosity |
|------------------|--------------|------------------|---|-----------|
| 30               | 0.1          | 1.16             | 0.67 | 0         |

**Table 1.** Concrete damaged plasticity [14].

![Eight node linear brick element and Truss T3D2](image)

**Figure 4.** Type element of concrete and reinforcement.

### 3. Result and discussion

#### 3.1. Load and displacement

Figure 5 presents the non-prismatic longitudinal section affect the load-displacement relationship between T-beam and I-beam. In order to investigate the effect of the non-prismatic longitudinal section on the structural behaviour of deep beam, the finite element simulation non-prismatic longitudinal section of T-Deep Beam (BT-2 and BT-3) and I-deep beam (BI-2 and BI-3) were compared to the prismatic longitudinal section of T-Deep beam (BT-1) and I-deep beam (BI-1) in terms of load and deflection.

As shown in Figure 5(a), the load-displacement of T-deep beams were linear up to yielding tension reinforcement. After yielding condition, the BT-1 showed a stiffer response compared to the BT-2 and BT-3. Then, the load capacity continued to rise but stiffness less than their initial ones until reaching the peak load. Finally, the load capacity of BT-1 and BT-3 deep beam model dropped. At the ultimate
condition, BT-2 include in T-deep beam model able to accommodate the higher peak load than others. BT-2 achieved the peak load of 2452.47 kN, and it has a displacement of 5.81 mm. Comparing to BT-2, BT-1 and BT-3 have a peak load reduction of 0.89%; 8.30% with a deflection of 5.51 mm and 4.94 mm.

According to the result show that the load capacity of the non-prismatic beam (BT-3) is 8.08% less than the prismatic beam (BT-1). It’s due to the reduction on beam height (d) along the span of the prismatic beam (BT-3) beam and the use of less tensile reinforcement when compared to non-prismatic beam (BT-1). Therefore, it lead to a reduction in the moment capacity that occurs in the beam. Based on the equation of moments developed by Untraur and Sies [16] mentions that the moment capacity of the deep beam has a linear relationship to depth of deep beam (d) and the tensile capacity of reinforcement (As ‘f’s’). It means that when the depth of a deep beam (d) and tensile capacity of steel reinforcement decreases, it will cause a reduced moment that could trigger declined of load capacity.

Meanwhile, the relationship between load capacity and mid-span of displacement in I-deep beams were illustrated in Figure 5(b). Meanwhile, the relationship between load capacity and midspan-displacement of I-deep beams were illustrated in Figure 4(b). The results show that load capacity of BI-1; BI-2 and BI-3 in the ultimate condition amounting to 2440.7 kN; 2391.66 kN; 2284.12 kN while the displacement that occurred in the midspan of the BI-1, BI-2 and BI-3 reached 5.4 mm; 5.37 mm; 4.56 mm. The maximum peak load occurs in the prismatic high beam models, namely BI-1.

From the analysis result on the I-deep beams, it shows that there is a significant difference in load capacity between the prismatic beam and the non-prismatic beam. The application of non-prismatic beams can reduce the load capacity by 2.01% of BI-2 and 6.42% of BI-3 when compared to non-prismatic beams (BI-1). It is also due to a reduction in beam height and tensile reinforcement capacity that affect the load capacity in non-prismatic beams. According to the moment capacity of the deep beam as reported by Untraur and Sies [16] that beam height (d) and tensile capacity of reinforcement (As.f’s) has a linear relationship with moment capacity. It means that there is decreasing of height and tensile reinforcement will effect of decreasing on the moment capacity of deep beams that could generate on less of the load capacity.

![Figure 5. Relationship between load and midspan-displacement of (a) I-deep beam and (b) T-deep beam](image_url)
So, it can be concluded that the non-prismatic effect on the longitudinal section will trigger the inertia value and different geometric dimensions which have an impact on the peak load received on the beam.

3.2. Ductility
The effect of the non-prismatic longitudinal section on the ductility of I-deep beam and T-deep beam was investigated in this study. According to the relationship between the load-displacement curve, the ductility was defined. The previous researchers use the ratio between the ultimate deflection and divided by the displacement at yield load as ductility calculation [2, 17]. Figure 7 shows the ductility value of the non-prismatic longitudinal section of the model for T-beam and I-beam. The ductility value of the BI-1 model is 3.91, the BI-2 ductility is 3.89, and the BI-3 ductility is 3.32. The maximum ductility value is found in the prismatic beam (BT-1). It can be concluded that the specimen non-prismatic (BT-1) survives better and is stable before collapsing than others. There is a significant difference of ductility between the prismatic between (BT-1) and non-prismatic deep beam (BT-2 and BT-3). Decreasing the ductility up to 17.77% of the BT-3; 0.51% of the BT-2 compared to the prismatic deep beam (BT-1).

3.3. Stiffness
Meanwhile in I-deep beam, the ductility value in the prismatic longitudinal section (BI-1) reaches 3.90 and non-prismatic longitudinal sections are 2.50 of BI-2 and 2.75 of BI-3. It can conclude that the prismatic longitudinal section shows good ductility than the non-prismatic longitudinal section of I-
deep beam. It shows that the maximum ductility value of I-deep beam and T-deep beam lies in the prismatic beam. It is because the cross-sectional height of the prismatic beam (I section and T section) is higher than the non-prismatic beam. Besides, the number of tensile reinforcement in prismatic beams (I and T) is higher than non-prismatic beams. By considering it, the prismatic beam to be able to support a higher ultimate displacement and it can trigger to reach high ductility.

The elastic stiffness of beam commonly obtained from the load-displacement curve that presents in Figure 5. The elastic stiffness is defined as the slope first stage of the load-displacement curve at the first crack [18]. Figure 8 shows that in this study, the stiffness value to be calculated is the elastic stiffness. This stiffness is a ratio between load and deflection at first crack. The maximum stiffness values on the I-deep beam and T-deep beam are obtained by the prismatic deep beam model (BT-1, BI-1). The results show that the stiffness value in the prismatic longitudinal section is higher when compared to the non-prismatic longitudinal section of I-deep beam and T-deep beam. It is due to the prismatic's deep beam has a more significant height than non-prismatic deep beam causes increasing in moment inertia which can trigger better stability compared to other deep beam models. According to the theoretical stiffness formula of a beam which has a linear relationship with the moment of inertia of the section [19]. It can prove that the effect of increasing inertia can increase the stiffness of the beam.

![Figure 8. Stiffness of varying longitudinal section on I-deep beam and T-deep beam.](image)

3.4. Failure mode

According to the simulation result, the crack distribution of beam could be seen by plastic strain output (PEMAG) in ABAQUS. As shown in Figure 9 illustrates the distribution of cracks along the I-deep beams in failure condition, where the sequence of colours from blue to reds represent the gradation of the plastic strain from lowest to highest respectively. At failure conditions, the simulation results show that the visualization of the crack distribution of prismatic's deep beam is almost similar with non-prismatic beams. It is indicated by phenomenon crack that starts from the support towards diagonally to the centre of the load. The failure mode is known as the shear mechanism.

In the 1987, the process of cracking can be explained in detail using the theory of nonlinear fracture mechanics and softening models of tensile concrete which were pioneer discovered by Hillerborg et al [20], then it was developed by Bazant [21] and Cedolin [22]. The cracks that occur in concrete are due to the tensile stress achieves the tensile of concrete material [23]. As the load increases, it also causes increases to stress on the reinforcement leading to yield. It could trigger the distribution of crack to become more extensive.

Figure 10 presents the distribution of crack in the T-deep beams in the ultimate condition. Based on the results of the crack pattern, it can be seen that the deep beam BT-1 and BT-3 experience flexible...
shear while the BT-2 beam experiences a shear failure pattern. This flexural shear failure pattern begins with the bending crack that occurs in areas that have a maximum moment and a small shear force. As the load increases, shear cracks appear in areas that have a large shear force, precisely in the bearing area leading to the load centre [24].

Figure 9. Crack distribution on varying longitudinal section of I-deep beam (a) BI-1, (b) BI-2 and (c) BI-3.

Figure 10. Crack distribution on varying longitudinal section of T-deep beam (a) BT-1, (b) BT-2 and (c) BT-3

4. Conclusion
According to the numerical simulation result show that the non-prismatic longitudinal section of the deep beam affect to flexural behavior such as load-displacement relationship, ductility, stiffness and mode failure. The non-prismatic longitudinal section is slightly decrease on the peak load compared to
the prismatic section. It caused by the reduction of height deep beam and the tensile reinforcement capacity trigger on decreasing inertia moment. Therefore, the load capacity of non-prismatic longitudinal section model is decrease. In addition, the ductility and stiffness of prismatic section shows good performance rather than non-prismatic longitudinal section. Otherwise, the shear failure mode between the prismatic and non-prismatic longitudinal section of I-deep beam demonstrates shear failure. Shear failure is represent the initial crack rise from the pin support approach to the center load. Meanwhile, the flexural-shear were occured on the prismatic and non-prismatic of T-deep beam.

5. References

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