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# Modelling the behaviour of steel fibre reinforced precast beam-to-column connection

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**Abstract.** The numerical behaviour of steel fibre reinforced concrete (SFRC) corbels reinforced with different fibre volume ratio subjected to vertical incremental load is presented in this paper. Precast concrete structures had become popular in the construction field, which offer a faster, neater, safer, easier and cheaper construction work. The construction components are prefabricated in controlled environment under strict supervision before being erected on site. However, precast beam-column connections are prone to failure due to the brittle properties of concrete. Finite element analysis (FEA) is adopted due to the nonlinear behaviour of concrete and SFRC. The key objective of this research is to develop a reliable nonlinear FEA model to represent the behaviour of reinforced concrete corbel. The developed model is validated with experimental data from previous researches. Then, the validated FEA model is used to predict the behaviour of SFRC corbel reinforced with different fibre volume ratio by changing the material parameters. The results show that the addition of steel fibre (SF) increases the load carrying capacity, ductility, stiffness, and changed the failure mode of corbel from brittle bending-shear to flexural ductile. On the other hand, the increasing of SF volume ratio also leads to increased load carrying capacity, ductility, and stiffness of corbel.

## 1. Introduction

Reinforced concrete (RC) is one of the most commonly used materials in the construction field since long ago. This material had been used for decades to build houses, bridges and even monuments all around the world [1, 8]. However, the trend had changed and the use of precast reinforced concrete (PC) had become popular in the construction field. It brings a lot of benefits compared to conventional cast in-situ RC structures. The PC components are fabricated in controlled environment which ensure the quality of the construction components [7, 10]. This increased building quality of a construction project. Besides, PC allows the use of smaller structural members which can enhance the appearance of a building [7]. In short, there are still many advantages of using PC compared to RC which it would makes PC as the future trend of construction, this includes the used of new composite high strength material and waste utilization as part of a component material. The invention is due to benefits of other materials to the precast components for a building. The benefits includes long lasting material, high strength and durable material, thermal and other important properties [18, 26].

The use of PC had been the future of construction field [18]. In a PC design, the connection of the precast member is the most important and critical component. Most of failure in PC structures is



caused by the failure of connection [10]. To date, there are many researches have been conducted on PC [1-18]. However, there is limited research focused on a connection of PC using SFRC [1]. In this research, behaviour of precast concrete corbel reinforced with different volume ratio of SF is investigated through modelling of a component in LUSAS analysis software. FEA model is developed by implementing constitutive models for the component. Experimental data from previous research is adopted to validate the prediction of the model. The validated model is used to model the behaviour of SFRC corbels reinforced with different SF volume ratio.

## 2. Literature Review

### 2.1. Reinforced Concrete

The ability of RC to provide a sufficient strength, stiffness and cost effective have made the RC as a first choice in construction industry [11]. Researches which aim to improve the ductility of plain concrete had been done throughout the time and finally found the approach to introduce the ductility into concrete is by adding a steel reinforcement which suggests the reinforced concrete [21-22]. To some extent, the steel reinforcement included both bars reinforcement and fibres reinforcement can provide sufficient tensile strength to improve the ductility of concrete to work under tension [23]. Besides, it also provides confinement effects in concrete [15]. The confinement effect is very important in a compression region of a member as it leads to improve the energy absorption capacity. Thus, steel fibre reinforcement is one of the alternatives approached in improved the ductility of a precast concrete component as it allows member to perform better under both tension and compression.

Bouafia *et al.* modified constitutive confined concrete model proposed by Mander *et al.* and the reliability of the modified model is supported with experimental data [2, 15]. Based on the comparison, the modified model shows a good agreement with experimental data for both circular and rectangular sections. To reduce the error in calculation, the equations proposed by Mander *et al.* is simplified by replacing unknown with constant values [15]. Concrete in tension is highly nonlinear as concrete in compression [16]. Due to this property, the model proposed by Massicotte and MacGregor assumed concrete as a linear-elastic brittle material with strain softening and suggested a post-cracking stress-strain relationship for the tensile part of the curve [16].

### 2.2. Precast Reinforced Concrete

Just like in a conventional RC structure, PC components such as beams and columns are constructed by using concrete material and steel reinforcements. The main difference between the conventional RC and PC structures are; method of construction and material used. In some application, a pre-stressed strand will be used to reinforce the precast products that cannot be found in conventional RC.

Corbel is a short cantilever projecting from column or wall and is commonly used in connection between beam and column PC. The main functions of corbel are to support other parts of a structure such as beams and transmit vertical and horizontal loads to the principal members [4, 6]. Since corbel is a part of precast component, researches also focused to the behaviour and capacity of corbel. Fattuhi [4] found out that the arrangement and amount of reinforcement in column has no significant effect on the strength of corbel. At most of the case, the shear span-to-depth ratio is the main factor that governs the capacity of corbel [6].

### 2.3. Steel Fibre Reinforced Concrete

SFRC was introduced to reduce the brittleness of concrete by introducing SF into concrete to act as the reinforcement. With the addition of SF, the properties of concrete will improve from brittle to ductile [9] as well as the failure mode. Concrete will losses its tensile resistance after the formation of macro cracks [5]. It is proven that SF could prevent the forming of macro cracks which leads to concrete spalling in concrete members [9] by forming more microcracks. All the microcracks are linked through the bridging effect of SF in concrete matrix [14] where it allows the transfer of stress

throughout the concrete member [17]. Therefore, SF could improve the post-cracking behaviour of concrete [9]. In some cases, adding of SF can reduce the steel reinforcement bars needed in a concrete structure [23].

Previous work proposed a compressive model based of concrete reinforced with hooked-end type of SF only [12]. The model can predict the strain at the compressive strength, elastic modulus of SFRC and applicable on a wide range of concrete strength. Actual compressive strength of SFRC is used in the model instead of compressive strength of plain concrete.

### 3. Methodology

2D model is used to predict the behaviours of corbel. Since the selected corbel specimen has a symmetrical shape, only half of the corbel was modelled to save the processing time without affecting the outcomes of analysis [3]. The boundary conditions at the top, bottom, and a side of column were assumed fixed. On the other hand, the reinforcement steel bars in column are not as the assigned parameters had considering the properties of such composite [4]. Next, the load was applied incrementally on a bearing plate made of an undefined strong material to prevent local crushing of concrete. Table 1 provides the model description.

**Table 1.** Model description

Model Definition	$V_f(\%)$	$f_{ct}$ (MPa)	$E$ (GPa)
Case Study Model	0	6.97	44.27
Reference Model	0	6.97	44.27
Model 1	0.5	8.24	32.80
Model 2	1	8.42	31.92
Model 3	1.5	9.89	31.04
Model 4	2	11.38	30.15

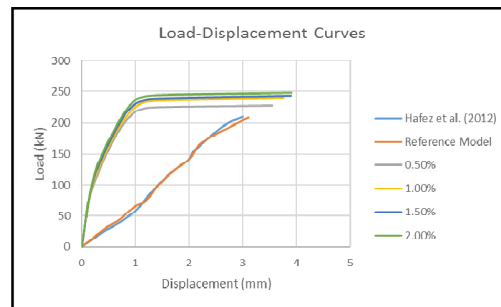
Reasonable assumptions were made for the properties which are not given in the reference paper. Steel was assumed to behave as an elastic-perfectly plastic material in both tension and compression. Material properties of steel were specified using the elastic and the plasticity of metal with plastic options. From the selected experimental data, yield stress of steel was given as 400 MPa. Young's Modulus and Poisson's Ratio were assumed as 210 GPa and 0.3, respectively.

To predict the nonlinear behaviour of concrete, compressive and tensile stress-strain curve were developed from [2] and [16] models, respectively. In LUSAS, concrete was attributed as an isotropic material. The material properties of concrete are specified as elastic and the plasticity of concrete with plastic options. Besides, the values of Young's Modulus, compressive and tensile stress strain relationship were derived from the selected models and assigned to define the concrete material. Poisson's Ratio for concrete was assumed as 0.2.

After the nonlinear FEA performed by LUSAS, a load-displacement curve is generated. The predicted load-displacement curve was compared to the curve from [6] experimental data. Several trials had been run to determine the suitable meshing shape and size that exhibit the same behaviour as experiment. Once both graphs show a good agreement, then the model is considered validated and can be used to predict the effects of SFRC on corbels [25].

### 4. Results and Discussions

Figure 1 shows the comparison of load-displacement curves. The maximum deviation of base model from experimental model is 13.2%, which is in between 10-15%. This indicates that the prediction of base model has a reasonable good agreement with experimental data [25]. Thus, this confirmed the validity of the FEA model to predict the effects of SFRC on corbels.



**Figure 1.** Comparison of load-displacement curves.

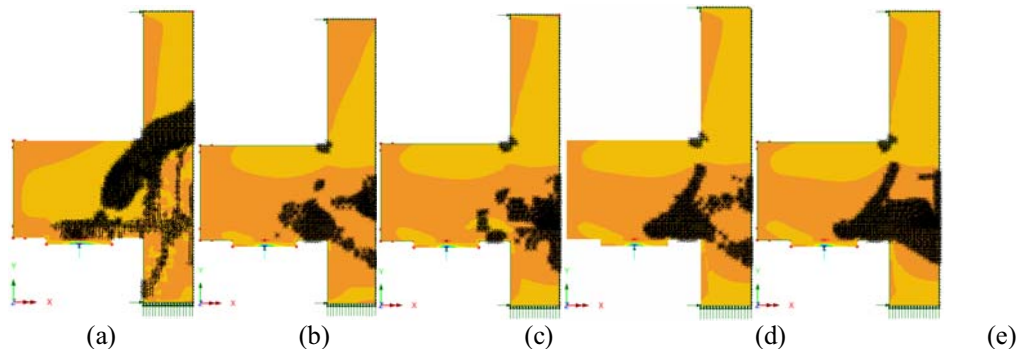
The study of the numerical effects of SFRC on corbels was carried out by increasing the SF volume ratio by  $V_f = 0\%$ ,  $0.5\%$ ,  $1.0\%$ ,  $1.5\%$ , and  $2.0\%$ . The compressive and tensile stress-strain relations for different SF volume ratio is developed from [12] and [13] models, respectively. The results of analysis are summarized in table 2. From the results, it shows that the ultimate shear load is increased drastically by 9.25% when SF is added into the concrete. The increase of ultimate shear capacity might due to the shear stress induced by increasing loads which absorbed by the fibres. The stress is distributed all over the structure by SF and reduced the stress acting on the critical parts of corbels. Besides, the ultimate shear load increases with an average value of 3.07% when the volume of SF increases by 0.5%. Thus, the increase of SF volume leads to the increase of energy needed to pull out the SF from concrete matrix [20], and results in greater load carrying capacity of corbels.

The ductility of corbel is assessed by ductility ratio. Values of ductility ratio of corbels is calculated by dividing the displacement at ultimate load with displacement at yield and the values are as summarized in table 2. From the values, it shows an increasing trend when SF is added. The ductility ratio is increasing with an average value of 8.95% when the SF volume increases by 0.5%. Next, the model illustrates a decreasing trend in displacement of corbels at the loading of 208.73kN when the volume of SF increases. The point of interest was set at 208.73kN because that is the ultimate shear capacity of Reference Model and displacement data at this point for all models are available. The decrease of displacement indicates that larger loading is required to cause the same displacement in corbel with the increase of SF volume. Hence, it can be concluded that the addition of SF could improve the ductility of corbel.

Stiffness of corbel is derived from the gradient of load-displacement curves (elastic part). The stiffness indexes for all the models are shown in table 2. The significant increase in the stiffness index from plain concrete to SFRC corbel indicates the stiffness of corbel improved with the addition of SF. Besides, the stiffness indexes are increasing at an average value of 11.80% when the SF volume increases by 0.5%. Therefore, increasing SF volume will improve the stiffness of corbel.

The numerical cracking and crushing pattern of the corbel models are illustrated in figure 2. The compressive stress is indicated by dark orange contour, while tensile stress is indicated by dark yellow contour. From figure 2, it is observed that all models exhibited tensile cracking at the region around bottom column-corbel interface and compressive crushing at the area around top column-corbel interface.

Besides, it can also be observed that the tensile cracks zone becomes larger when the amount of SF increased. By observing the crack and crush zone of base model, it shows that the corbel failed in bending-shear as there is an obvious crack that slices through column-corbel interface. Besides, the failure was also accompanied by brittle failure mode as the concrete at the region of top column-corbel crushed. However, by comparing the base model with other SFRC models, it clearly shows that the addition of SF reduced the area of compressive crushing zone significantly and completely removed the crack that slices through the column-corbel interface. Hence, it can be concluded that addition of SF altered the failure mode of corbel from bending-shear accompanied with brittle failure to flexural ductile failure mode.



**Figure 2.** Stress distribution and cracking zone: (a)  $V_f = 0\%$ , (b)  $V_f = 0.5\%$ , (c)  $V_f = 1.0\%$ , (d)  $V_f = 1.5\%$ , (e)  $V_f = 2.0\%$ .

**Table 2.** Summary results for models.

Model Definition	$P_{ult}$ (kN)	$\Delta P_{ult}$ (%)	$\delta_{ult}$ (mm)	$\Delta \delta_{ult}$ (%)	$\mu$	$\Delta \mu$ (%)	S.I	$\Delta S.I$ (%)
Case Study Model	210.00	-	3.01	-	1.03	-	75.13	-
Reference Model	208.73	0	3.10	0	1.08	0	71.77	0
Model 1	228.03	9.25	3.55	14.52	1.46	35.19	202.78	182.54
Model 2	239.92	14.94	3.76	21.29	1.57	45.37	212.24	195.72
Model 3	243.19	16.51	3.89	25.48	1.66	53.70	216.19	201.18
Model 4	247.25	18.45	3.91	26.13	1.75	62.04	228.19	217.95

## 5. Conclusion

Based on the results and discussions, conclusions can be drawn as summarized below:

- i. A reliable nonlinear FEA model to represent the behaviours of concrete corbels was developed by implementing models from [2] and [16]. The capability of the model to predict the behaviours of concrete corbels subjected to vertical load only is validated with experimental data from [6].
- ii. Addition of SF caused the load-carrying capacity of corbels to increase drastically by 9.25% due to the distribution of excess stresses by discrete SF away from critical parts of the corbels. Besides, the load-carrying capacity of SFRC corbels increase by an average of 3.07% when SF volume increases by 0.5%. This is contributed by the pull-out strength of SF.
- iii. Corbels with SFRC can deform greater before failure compared to plain concrete corbel. This indicates the ductility of corbel is improved with the addition of SF and it is supported by the increasing values of ductility ratio. The ductility ratio increased with an average value of 895% when the SF volume increased by 0.5%. This indicates that SFRC corbels with higher volume of SF can deform greater before failure. This shows that the increasing volume of SF improved the ductility of SFRC corbels.
- iv. Addition of SF caused an increase of 182.54% in stiffness. Besides, the stiffness index is increasing with an average value of 11.80% when the SF volume increases by 0.5%. This indicates the SF can improve the stiffness of corbel.
- v. Increase of SF volume enlarges the tensile crack zone in corbels due to the improved ability to propagate cracks by the bridging effect of SF and more microcracks are formed. Failure mode of corbels changed from bending-shear with brittle failure to flexural ductile failure mode with the presence of SF.



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