Assessment of Existing Concrete Half-Joint Structures Using Strut And Tie Analysis And The Development of The Yield Assumption Method

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Abstract

During the 1960s, half joints were commonly used in the design of concrete bridges. Due to the age and condition of such structures, it was necessary to carry out assessments of structural resistance of the half joint structures. The most commonly used method of assessment for half joint structures is the Strut &Tie Method (STM). However in many cases a simple application of the STM without further iteration can result in an underestimate of the structural resistance. For this reason, other analysis methods were developed over the period. Alternative methods include the upper bound collapse mechanism approach (CMA) and the development of the yield assumption method (YAM) as described in this paper. Experimental work was carried out by Desnerck et. al 2016 on a series of half joint beams. The aim of this paper is to compare the experimental results with analytical methods and to ascertain the efficiency of recently developed assessment method YAM. The reinforcement layout and details are taken from the experimental work and analysed using STM and YAM. It was found that the resistance obtained from YAM matches the experimental work within an error of 7%.

Keywords: Half joint, strut and tie method, yield assumption method.

1. INTRODUCTION:

The half joint form of structure was commonly used in bridges during the 1960s (Northing 2015). This concept enabled efficient installation of a centrally supported deck, and allowed a reduced construction depth by recessing the supporting corbels into the depth of the beams supported. (Mattock 1979). The other benefits of half-joint structures include the ability to standardise the design of the supported span, enabling a modular design approach to be used for a series of bridges. However, there are some disadvantages associated with this form of construction. The most prominent is related to the lack of water tightness of the joint itself resulting in deterioration (Desnerck et. al 2017). Seepage of chloride-contaminated water can accumulate in the lower half joint, resulting in corrosion of steel reinforcement. Due to access issues, half-joints can be difficult to inspect as easily as other structures and therefore there can be uncertainty about the condition of reinforcement. Limited guidance is available for the assessment of concrete half-joints. In the UK, the DMRB standards and advice notes BD44, BA39, BA51, and IAN 53 give some guidance about the consideration of section loss of reinforcement and method of assessment for half joint. These documents are very useful but are based on limited data and do not give specific guidance on the combined effect of reinforcement deterioration, concrete spalling and improper detailing at the same time.

In the practical assessment of half joint structures various analytical methods have been proposed. These include: strut and tie method (STM); collapse mechanism approach (CMA); and yield analysis method (YAM). STM is a well-known method, most commonly used for design of new structures as set out in EN1991-1-1, and is based on the lower bound theorem of limit analysis, so it generally provides conservative estimates of resistance. CMA is an implementation of the upper bound theorem of limit analysis, therefore it can give unsafe estimates of resistance unless fully optimised. Nevertheless it has been proposed in the assessment of some half-joints as a departure from the standards. The third method YAM is presented in this paper, and is a development of STM that enables the conservative estimates from STM to be improved, whilst still giving a safe estimate of resistance. The brief procedures of these three methods are detailed in section 2.

Experimental work carried out by Desnerck et. al (2016 & 2018) considered four large scale half joint details with different reinforcement arrangements. The size of specimen and reinforcement details have been taken from the experimental work by Desnerck et. al (2016 & 2018) for this study. The outcome of the experimental work by Desnerck et. al (including failure load and failure mode) have been theoretically analysed using the STM and YAM methods. The reinforcement details and layout considered for these two methods are shown in Figure 1. Comparison was carried out with the experimental output and the efficacy of each method is discussed. The aim of this paper is to compare the experimental results with analytical methods and to ascertain the efficiency of the recently developed assessment method YAM.

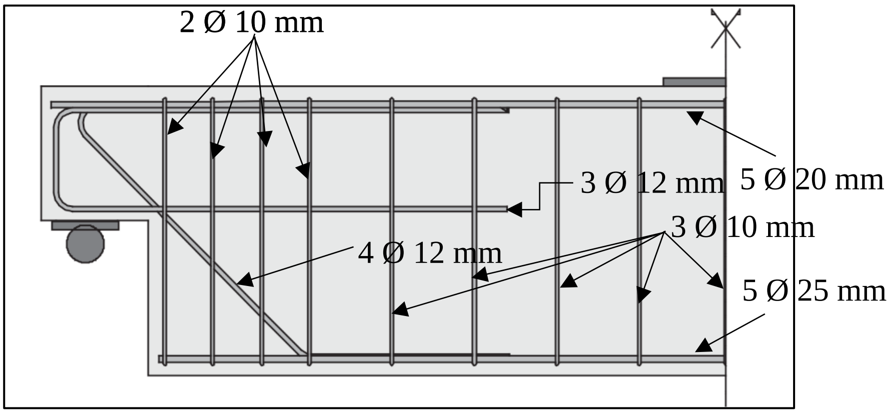

Figure 1: Reinforcement layout (Desnerck et al 2016)

2. METHODOLGY

2.1 Assessment of half joint structure in accordance with STM (using the default models in BD 44/15)

According to BD 44/15, assessment of half joint structures should be done using the Strut-and-Tie Method (STM). This method comprises idealising the forces in the half-joint using concrete struts, reinforcement ties and connecting nodes. STM is a lower bound method which requires that the equilibrium and yield criteria to be satisfied.

BD 44/15 permits two simple strut and tie models (orthogonal and inclined) to be analysed. The load carrying capacities of the half-joint structure is obtained by taking the results of the two models. Based on the reinforcement layout of Figure 1, the models, as shown in the Figure 2, are used for assessing the capacity of half joint in accordance with BD 44/15.

It is recognised that the STM can also be carried out using alternative arrangements of struts and ties, which might give a better result. However, in this study the results for the STM method are based on an assumption that the simple models of BD44/15 are applied directly without further iteration. This is a common interpretation of the BD44/15 content by practising engineers. It should be noted that a length of horizontal reinforcement was assumed as it was not indicated in the study by Desnerck et. al 2016. The assumed length will provide a full anchorage condition for the horizontal tie at the node in the orthogonal model. Hence, this may overestimate the load carrying capacity of the structure. The same assumption has been adopted for the Yield Assumption Method (YAM).

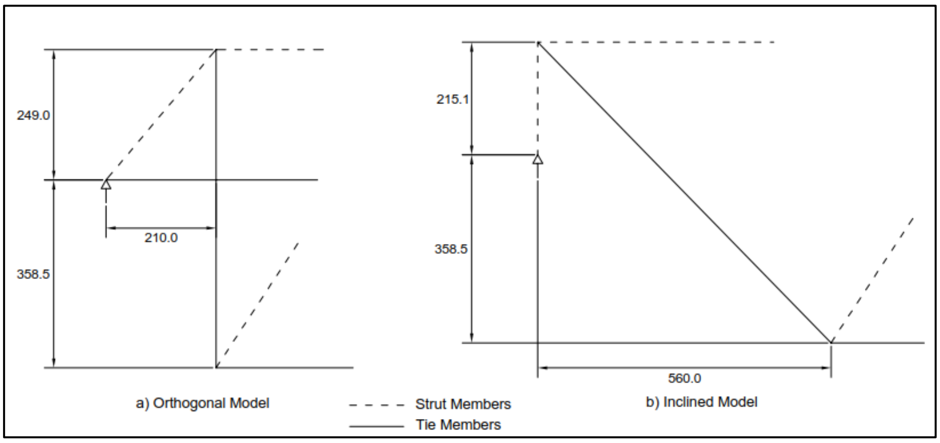

Figure 2: Strut-and-tie models in accordance with BD 44/15

2.2 Assessment of half joint structure in accordance with YAM (DAS ID:80895)

The existing STM (BD 44/15) has been adopted due to the simplicity of this approach and the capacity of the structure can be calculated by hand. Nowadays, a complex strut-and-tie model can be proposed and analysed with the help of computer aids (e.g. MIDAS Civil 2018 v2.1). The Yield Assumption Method (YAM) proposes a combined strut-and-tie system to estimate the capacity of the half-joint structure. In the system, the tie members that are fully anchored can yield one by one starting with the most critical member. Once a tie member reaches its yield condition, this tie, will be replaced with a force equal to the yield capacity of the reinforcement and applied to the relevant nodes to represent the tie in the system. Figure 3 shows the combined strut-and-tie system which is used to calculate the capacity of the half-joint structure.

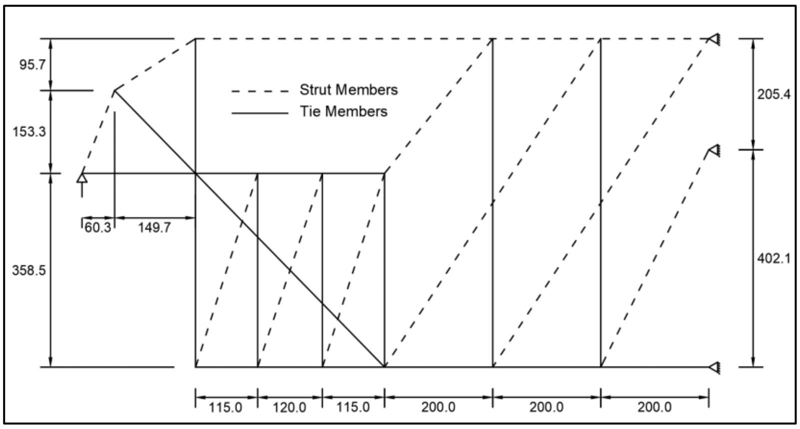

Figure 3: Proposed YAM model

3. RESULTS AND DISCUSSION

Table 1 details the results from the three methods of half joint assessment as explained in section 2. It should be noted that all the partial safety factors have been set to 1.0 for the evaluation purpose. It can be observed that difference of STM and YAM are 36%, and 7%, respectively, as compared to the experimental work. The results demonstrated that the capacity obtained from the YAM are matching with the experimental results within an error of 7%. It should be noted that STM is underestimating the capacity of the half -joint structure whereas the YAM is slightly over estimated the capacity of the half-joint structure. This may be due to the assumption made for length of the horizontal reinforcement. However, once including the partial safety factors and design strength of the materials, the STM will well underestimate the capacity of the half-joint structure.

Failure mode for each method and experimental work are also presented in the Table 1 and Figure 4. It can be observed that the failure mode determined by the YAM is comparable to the experimental work. It should be noted that failure cannot be determined by STM. In both cases, horizontal and inclined reinforcement reached to its limit and resulted in the failure of the half joint. This has developed further confidence in utilising the YAM for the assessment of half joint structures.

Table 1: Half Joint Assessment Results

Method	Maximum Half Joint Capacity (kN)	Ratio (Analytical / Experimental) %	Failure Mode
STM	256.7	64	Yielding of the inclined bars and the 1st vertical link.
YAM	431.9	107	The top 2 elongated reinforcement are the horizontal reinforcement and the inclined bars based on the strain analysis.
EXP	402.3	-	Due to the rupture of inclined bars and the horizontal

reinforcement.

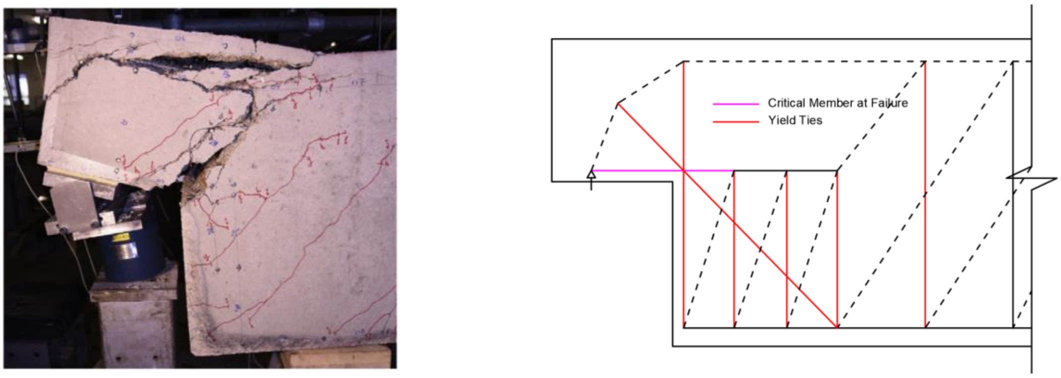

Figure 4: Comparison of Failure Mode (Experimental vs YAM)

5. CONCLUSION

The outcome of the experimental work by Desnerck et. al which include failure load and failure mode were taken in this study and theoretically analysed using STM and YAM methods. The conclusions are as follows:

1. The difference of failure load for the half joint from STM and YAM are 36% and 7%, respectively, as compared to the experimental work.
2. The capacity obtained from YAM is matching with the experimental work within an error of 7% difference.
3. Once including the partial safety factors and design strength of the materials, the STM will well underestimate the capacity of the half-joint structure.
4. Failure mode was observed by the YAM is comparable to the observation in the experimental work.

This study has suggested that YAM is more suitable method for the assessment of half joint structures than STM. However, only one experimental result has been assessed in this study, therefore, it is recommended to carry out further checks with other experimental results to confirm the adequacy of YAM.

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