ASSESSMENT OF BARS LAYOUT ON THE STRENGTH OF EXISTING RC HALF-JOINT STRUCTURES USING THE PLASTIC REDISTRIBUTION METHOD

Eirini Balantina[a], Shunde Qin[b] and Furqan Qamar[c]
a: Engineer, WSP UK
b: Engineer, WSP UK
c: Corresponding Author. Principal Engineer WSP UK.
Email: Furqan.Qamar@wsp.co.uk

Abstract - Half-joints structures are commonly used during the 1960s. Construction of concrete bridges using half joint was simplified due to the central spans being able to be lifted into place once the cantilevered spans were constructed. In this form of construction, the beam geometry consists of a reinforced concrete nib with a full depth section adjacent to it; the force transfer from the load point through the nib and to the full depth section is relying on the reinforcement detailing, which can vary from the as-designed drawings. Engineers who are assessing the existing half joints structures may be challenged by missing bars or reinforcement layout not compliant with the current standards. Experimental work was carried out by Desnerck et al. to identify the consequences of a series of reinforcement configurations on the capacity (load) of half joint's beams. The reference beam designed as per prevailing practice was analysed by Qamar et al. using both Strut and Tie Method (STM) and Plastic Redistribution Method (PRM), previous known as Yield Assessment Method (YAM). The aim of this paper is to compare the experimental results of the beams having missing reinforcement with analytical results using the plastic redistribution method. The effect of missing bars was not considered in the previous study. The reinforcement layout and details, covering either missing horizontal reinforced bars, missing diagonal reinforced bars or a decreased amount of shear bars, were taken from the Desnerck et al. experimental work. It was found that the resistance obtained from PRM differed with the experimental data by maximum 12%. The findings of both the PRM assessment and the empirical works suggest that the consequence of improper bars layout is evident on the strength of existing reinforced concrete half-joint structures.

Keywords: Half Joint, Plastic Redistribution Method, Strut and Tie, Yield Assumption Method.

1. INTRODUCTION:

During the 1960s and 1970s several half joint structures introduced into bridge deck construction. The main advantage of this construction type is the efficient installation of a centrally supported deck, allowing a reduced construction depth by recessing the supporting corbels into the depth of the beams supported. [6]. Design of the supported spans on half-joint structures can also be standardised which facilitates a modular design approach to be used for a series of bridges. Nevertheless, reinforced concrete half-joint structures are susceptible to concrete deterioration and reinforcement corrosion due to leakage of water and chlorides ingress through the joint [2,3]. Loss of reinforcement and concrete degradation are hidden problems which cannot be easily inspected in this type of construction. In addition, another challenge which is commonly encountered by the engineers when assessing the integrity of existing half-joint structures is the lack of information regarding the as-built layout of the existing reinforcement. In many cases, there are inconsistencies between the structures and the as-designed drawings, or the reinforcement details are not compatible with the current standards. With respect to half joint bridge assessment in the UK, the DMRB standards and advice notes BD44, BA39, BA51, IAN 53 and CS 466 [7,8,9,10] provide engineers with guidance about the assessment methods and the challenge of reinforcement section loss.

Experimental work carried out by Desnerck et al. [3,4] investigated four different cases to determine the consequences of missing reinforced bars on the load failure and mode (failure) of half joint structures. The load carrying capacity of the half joints beams decreases as a result of decreasing the reinforcement amount while their failure mode is influenced. By eliminating the diagonal bars or U-bars in the nib, a failure at nib is observed, while reducing the shear reinforcement in the half joints beams results to a failure in shear across the full-depth section. The highest reduction in failure load had been observed in the beam having no diagonal reinforcement. The lowest reduction on failure load had been observed when the shear reinforcement was reduced [2].

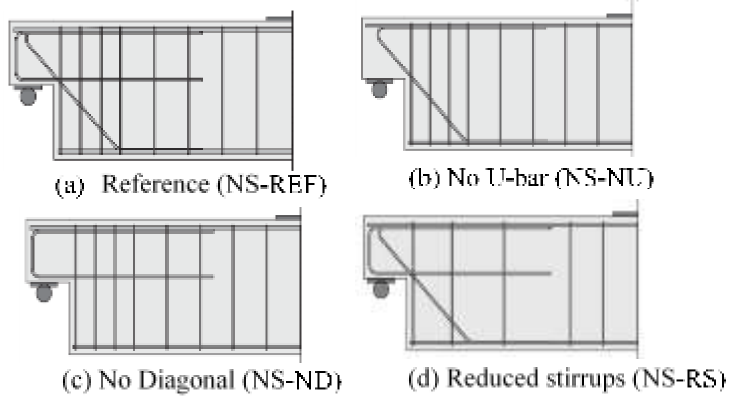


Figure 1: Reinforcement layout (Desnerck et al 2016)

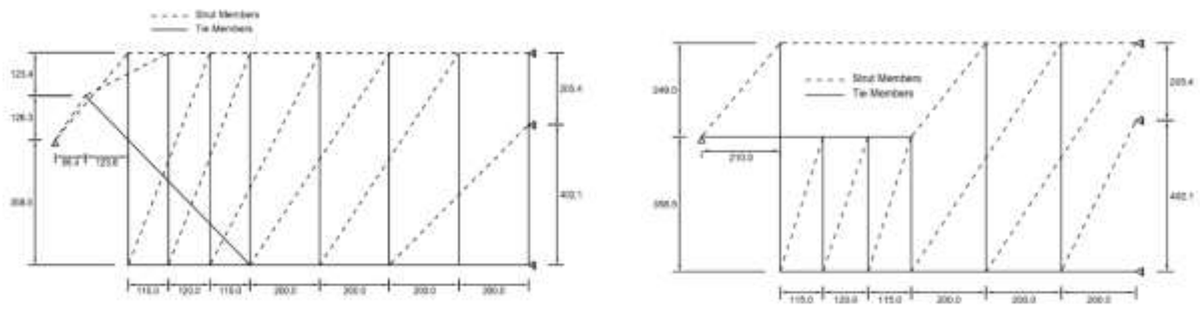
The outcome of the experimental test program by Desnerck et al. for the reference specimen (complete reinforcement arrangement) had been analysed using STM and YAM by Qamar et al.; the resistance obtained from YAM matched the experimental work within an error of 7%. The aim of this paper is to discuss the efficiency of the PRM analytical method, previous known as YAM, by comparing the experimental results with the results of the PRM for the other three specimens. In accordance with CS 466 [11], the effects of plastic redistribution may be considered to improve the conservative estimates from the strut-and-tie analysis, whilst still giving a safe estimate of resistance. The reinforcement details and layout considered including the reference specimen were taken from the experimental work by Desnerck et al. and are shown in Figure 1.

2. METHODOLGY

2.1 Assessment of half joint structure in accordance with PRM

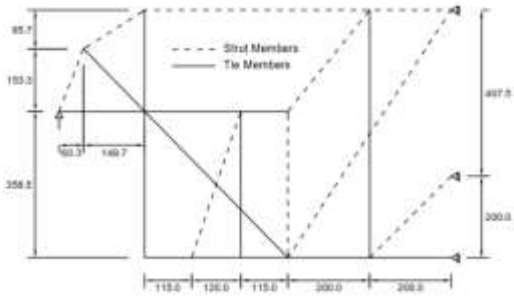
The Plastic Redistribution Method (PRM) proposes a combined strut-and-tie system to estimate the resistance of the half-joint structure. The three combined strut- and-tie models utilized to evaluate the capacity of the half-joint beams with reduced reinforcement are shown in Figure 2, and they have been analysed using MIDAS Civil 2018 v2.1. The tie members, which have been assumed to be fully anchored for the current analysis, yield one by one starting with the most critical member.

When the critical tie member starts yielding, it is replaced in the model with a pair of internal forces equal to the yield resistance of the reinforcement, applied to the relevant nodes to represent the tie in the system. The model is analysed to determine the redistributed forces in the other ties and struts. This process is followed until all tie member reach their assessment yield resistance or the model becomes unstable. No other parameters or constitutive model is considered in this method.



(a) No U bar (NS-NU)

(b) No Diagonal bar (NS-ND)



(c) Reduced stirrups (NS-RS)

Figure 2: Proposed SRM models

3. RESULTS AND DISCUSSION

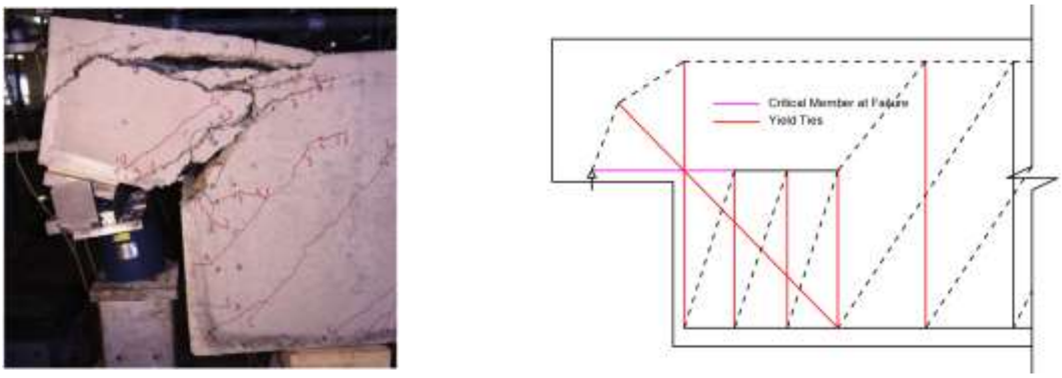
The highest predicted failure load of 431.9kN was obtained using the PRM for the reference specimen differed with the empirical data by 6.8% (Table 1). The failure of the half joint occurred when the horizontal and inclined reinforcement reached their yield resistance and caused half joint failure. The same failure mode was also observed during the empirical testing; the half-joint failure observed because of rapture of the U-bar and diagonal reinforcement at the re-entrant corner location. By reducing shear reinforcement amount, the capacity of the beam was reduced by 10.9 %, resulting in 385 kN failure load in model, which differed to the failure load from the experimental work carried out by Desnerck et al (358 kN failure load) by 8%. However, the PRM failure was occurred in the horizontal reinforcement (U-bar) and not due to a full-depth shear failure as recorded during the experiments. This may be explained due to the assumption that was made that the horizontal reinforcement was fully anchored, preventing from developing cracking in the full depth area and resulting in a theoretical failure at the corner of re-entrant.

It is also worth to note that all the partial factors were set to 1.0 for the plastic redistribution assessment. The absence of the horizontal U- bars, reduced the beam capacity, resulting in 237.6 kN failure load and reducing the half joint resistance by 45% compared to the reference specimen. The predicted failure load and empirical value differ by 12%. The highest decrement had been observed with elimination of diagonal reinforcement, resulting in 227.6 kN predicted failure load which differs to the empirical load by 7 %. The resistance of the half joint without the diagonal bars was decreased by 47% in comparison with the capacity of the reference model calculating with the PRM. The failure of the NS-ND and NS-NU specimens occurred because of diagonal and horizontal reinforcement in the corner of re-entrant, respectively, and it matches the failure mode observed during the experimental works.

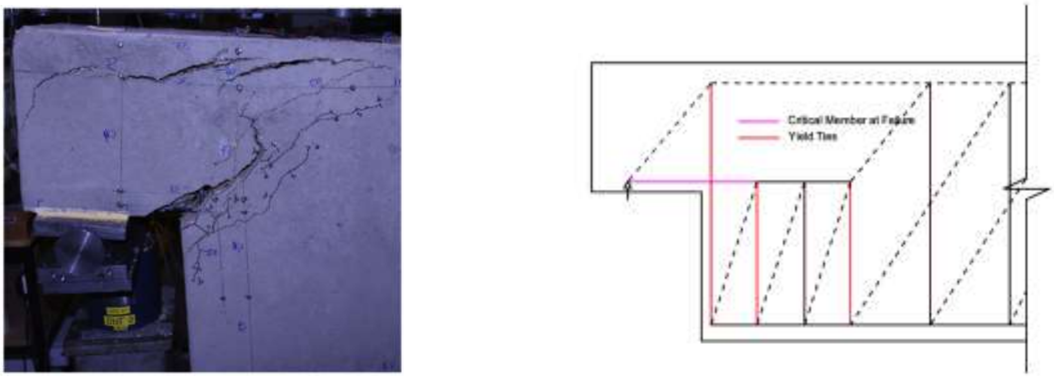
The resistance of the half joints without U-bar and diagonal reinforcement, calculated with the PRM, was slightly less as compared to the experimental results obtained by Desnerck et al. In contrast, for both the reference and with the decreased shear bars samples, the resistance of the half joint was slightly increased in comparison with the experimental work. The failure load and failure mode for all specimens for PRM and experimental work are shown in Table 1 and Figure 3.

Table 1: Half Joint Assessment Results

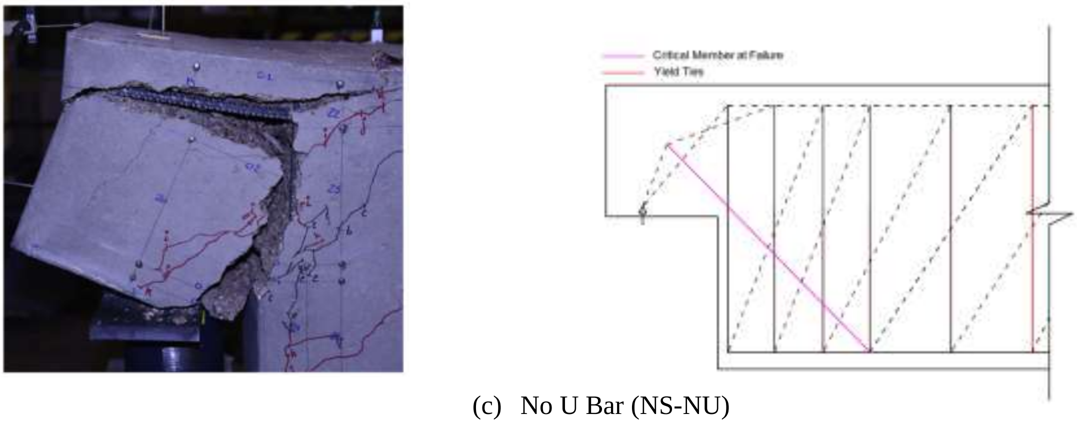
Specimen	Maximum Half Joint Capacity (kN)			Failure Mode	
	Experimental Results	**SRM**	**Ratio (Analytical / Experimental) %**	**Experimental Results**	**SRM**
NS- REF	402.3	431.9	6.8%	Due to the rupture of inclined bars and the horizontal reinforcement.	Top 2 elongated reinforcement are horizontal reinforcement and the inclined bars based on the strain analysis.
NS- ND	244.9	227.6	7%	Due to the rupture of the horizontal reinforcement in the corner of re-entrant.	The top elongated reinforcement is the horizontal reinforcement based on the strain analysis.
NS-NU	295.8	237.6	12%	Because of rupture of inclined reinforcement at re-entrant corner.	The top elongated reinforcement is the inclined reinforcement based on the strain analysis.
NS-RS	358	385	8%	Failure in shear across full-depth section of beam.	The top elongated reinforcement is the horizontal reinforcement based on the strain analysis.



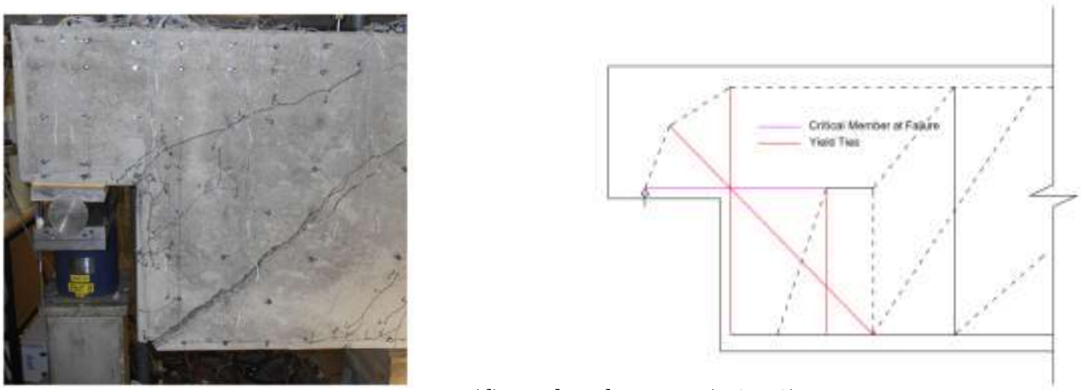
(a) NS-REF



(b) No Diagonal Bar (NS-ND)



(c) No U Bar (NS-NU)



(d) Reduced stirrups (NS-RS)

Figure 3: Comparison of Failure Mode (Experimental vs SRM)

5. CONCLUSION

The findings of the empirical work carried out by Desnerck et al., which assesses the half-joints structure's response. The structures having non-compliant reinforcement arrangements were analysed in this study and compared with the analytical results using the PRM. Following are concluded from current study:

1. The highest reduction in failure load had been observed in model having no diagonal reinforcement, resulting in 227.6 kN predicted failure load and showing 47% load decrement in comparison with the capacity in base model.
2. With decreasing the shear reinforcement amount, the capacity of beam was reduced by 10.9 %
3. The predicted failure load and empirical value differ by 6.8%, 7% ,8% and 12% for base model, the model having no diagonal reinforcement, the model having reduced stirrups and the model without U-bar, respectively.
4. The failure for the reference model, the model without U-bar and with absence of diagonal reinforcement which was observed by the PRM matches the brittle failure observed at the corner of re-entrant during empirical works.

The findings of both the PRM assessment and the empirical works suggest that the consequence of improper bars layout is evident on the strength of existing reinforced concrete half-joint structures. However, by decreasing the quantity of the shear bars, the failure occurred in the horizontal reinforcement at the corner of re-entrant and not because of a full- depth shear failure as recorded during the experiments. This may be explained due to the assumption that was made that the horizontal reinforcement was fully anchored, preventing from developing cracking in the full depth area and resulting in a theoretical failure at the re-entrant corner. Additional analysis is required in order to determine the potential effect of the anchorage on the failure mode and failure load of models with non-compliant reinforcement details. Other parameters like strain and crack evaluation will be considered in the future works. The work from this study gives a better confidence in the PRM assessment and can be used in the assessment of half joint structures which are biggest problem in the construction industry. This is due to unknow reinforcement and their condition.

ACKNOWLEDGEMENTS:

The authors would like to thank WSP UK Ltd as an organisation to give opportunity to carry out this study. The authors are also thankful for the proofread by Dr. Majid Ali. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

REFERENCES:

[1] Standards Institution. (2002) BS EN 1991-1-1:2002. Eurocode 1: Action on Strucutres. Part 1-1. *London, British Standards Institution.*

[2] Desnerck, P., Lees, J. M. & Morley, C. T. (2016) Impact of the reinforcement layout on the load capacity of reinforced concrete half-joints. *Engineering Structures*, 127 227-239.

[3] Desnerck, P., Lees, J. M. & Morley, C. T. (2017) The effect of local reinforcing bar reductions and anchorage zone cracking on the load capacity of RC half-joints. *Engineering Structures*, 152 865-877.

[4] Desnerck, P., Lees, J. M. & Morley, C. T. (2018) Strut-and-tie models for deteriorated reinforced concrete half-joints. *Engineering Structures*, 161 41-54.

[5] Departure DAS ID 20188 – Utilising the vertical links in strut-and-tie method for half-joint assessments

[6] Mattock A H. (1979) Design and behaviour of dapped end beams. *PCI Journal*

[7] The Highways Agency The assessment of concrete Highway Bridges and Structures. BD 44/15. *Highway Structures: Approval Procedures and General Design*, 3 (4)14.

[8] The Highways Agency. Assessment of reinforced concrete half-joints. BA 39/93. Highway Structures: Approval Procedures and General Design, 3(4)6.

[9] The Highways Agency The assessment of concrete structures affected by steel corrosion. BA 51/95. *Highway Structures: Approval Procedures and General Design*, 3 (4)13.

[10] The Highways Agency Concrete half-joint deck structures. IAN 53/04. *Highway Structures: Interim advice notes*.

[11] Highways England Risk management and structural assessment of concrete half-joint deck structures. CS 466. Highways Structures & Bridges Inspection & Assessment