International Journal For Technological Research In Engineering
Volume 6, Issue 7, March-2019 ISSN (Online): 2347 - 4718

# EXPERIMENTAL STUDY OF TWO STRUT AND TIE MODELS FOR DAPPED-END BEAMS

Juan Rentería-Soto[1], Juan José Cruz-Solís[2], Julio Roberto Betancourt-Chávez[3], Rajeswari Narayanasamy[4]
[1,3,4]Research-professor at FICA-UJED, Gómez Palacio, Durango, México.
[2]Research-professor at FI-UNACH, Tuxtla Gutierrez, Chiapas México.

***Abstract: The term corbel is given to the element projecting from a column or from the end of a beam. The corbels have a geometrical discontinuous section that makes the design difficult, because the stresses present a non-linear distribution. The objective is to analyze two strut and tie model (STM), for reinforced concrete dapped-end beams. Two STM were designed, one orthogonal and the other with a main diagonal tie. They were taken to the fault and it was obtained that a model with the diagonal element presents better behavior***
***Keywords: dapped-end, reinforced concrete, strut and tie model, stress distribution.***

## I. INTRODUCTION

The term corbel is given to the element projecting from a column or from the end of a beam, that is, forming a cantilever [1]. The corbel is articulated connections used as a vertical support for bridge beams and for precast structural systems. The corbels have a geometrical discontinuous section that makes design difficult because the stresses present a non-linear distribution according to the San Venant principle [2] and generate cracks at low load.
The analogy of a truss that transfers the load is not new, dating back to the late XIX century when Ritter [3] and Morsch [4] presented that analogy. [5] presented the classification of a structure based on the distribution of stresses, where Bernoulli´s theory applies, they called B region and where the stresses have a non-linear distribution they called D region by perturbed or discontinuity, the non-linearity in the stress is generated by a concentrated load, supports, section changes. The corbels at the end of the beams are called dapped end beams (DEB), which according to [6] are elements that stimulate the construction of precast structures, as they help to reduce the height of the floor and give greater lateral stability to the beams. The DEB work differently to the corbels in columns, the last ones, transfer the load by a strut to the column, while the DEB does not have support at the bottom, having the need to move the load towards the upper end [6].
The study on the application of the strut and tie model in DEB is broad and has made great advances in knowledge about behavior. [7] experimented with pre-stressed trimmed ends that they called stepped beams, evaluated the shear that occurs in the elements and the contribution of reinforcing steel and prestress to support the shear, determined that shear force that generates the cracking in the reentrant corner is equal to the shear that resists the concrete. Later, [8] analyzed disturbed regions by STM, for DEB they proposed a truss model that does not match with all the criteria since it has a strut normal to the trajectory that follows the cracking pattern of the reentrant corner, that makes it inconsistent. In [9] they evaluated 24 ends trimmed (dapped end beams) and estimated the shear based on a simple reinforcement model very similar to that of [8] but the inclined struts were oriented in such a way that they are consistent with the cracking patterns. In [10] an experimental analytical study is presented where they evaluated the design method by strut and tie model, found that it is very useful but each model has its own behavior that differs from the others. [11] mentions that the STM is very useful, but it is important to propose a model that correctly describes the distribution of stresses since it is an area where they present a non-linear distribution; it was based on the MPT proposed in [8] and later presented in [12] which corresponds to the failure modes found up to that moment, modifying it according to the advances in the description of the cracking.
In [13] evaluated the shear strength of trimmed ends, designed the elements using a strut and tie model proposed in ACI-ASCE committee 445 [14], finding that the resistance varies significantly when changing the ratio, a/d and the angle of inclination of the main strut, [15] comment that the inclination of the main strut should not be less than 45°. In [16] proposed an STM for DEB, a load of failure was estimated according to the PCI [17], BS [18], EC [19] and ACI [2], showing better results ACI and PCI, the model does not behave favorably since some elements have a null load.
In [20] conducted a study of cut-off ends (dapped-end beams) to evaluate the incidence of the amount of reinforcing steel and the capacity of the concrete, designed 4 beams based on the PCI [17] and obtained analytically the load capacity by means of STM based on FIP [21] which is not consistent with the behavior presented so far. For dapped end beams (half-joints) cracking initiates 20 to 33% of the failure load and always at the reentrant corner at approximately 45° according to [22].
The present study has the objective of analyzing two STM, for reinforced concrete dapped-end beams and to compare the results of each of them.

## II. MATERIALS AND METHODS

Two STM were designed, to transfer the load to zone B, the dimensions of the beam were: 500 mm height by 250 mm in depth, at one end 250 mm of the total height was cut, giving a cut-off section of 250 mm per side, as shown in fig 1.

  

*International Journal For Technological Research In Engineering*
*Volume 6, Issue 7, March-2019* *ISSN (Online): 2347 - 4718*

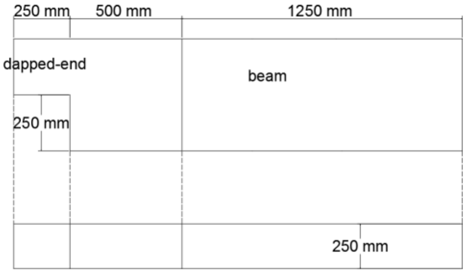


Fig. 1. Dimensions of the specimens.

The proposed section was modeled in commercial finite element software to identify the direction of the trajectory of the principal stresses. Once the values of the main stresses were obtained, the two MPT were designed, model 1 (M1) has an orthogonal configuration (Fig. 2), and the second one (M2) has a strut that crosses the section change border with an inclination equal to the direction of the main stresses in the reentrant corner (Fig. 3).

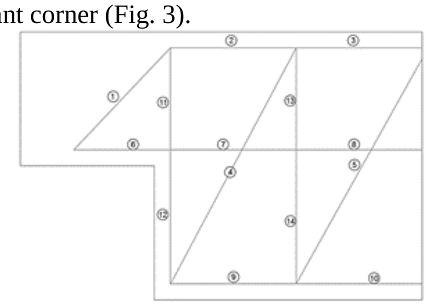

Fig. 2. Orthogonal model (M1).

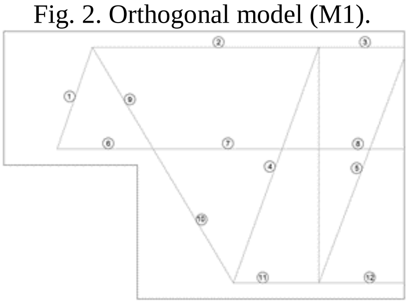

Fig. 3. Diagonal model (M2).

*A. Materials*

The specimens were manufactured with concrete of normal weight, and strength of 27.45 MPa with an additive to accelerate the setting.

The steel used was grade 42, with a yield strength of 412 MPa, the characteristics and specifications were obtained from the factory.

*B. Experimental design*

The reinforcement obtained from the design is presented in fig. 4 and fig. 5, and was carried out in accordance with [2], the specimens were instrumented with strain gauges in the steel, placed in zones identified with stress concentration as shown in fig. 6 and fig. 7 and the displacement at the edge of the nib was measured, load was applied with the help of a hydraulic cylinder of the brand Enerpck with capacity of 20-ton and pump of the Omega brand. The load increments were 500 kg until the failure, in each load increment the gauges were read. The displacement of the outer end of the corbel was monitored.

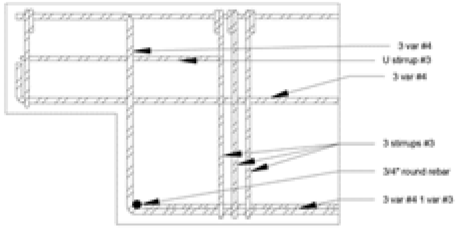


Fig. 4. Orthogonal reinforcement (M1).

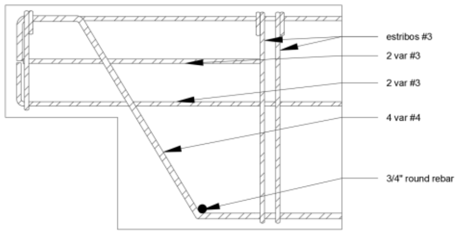


Fig. 5. Diagonal reinforcement (M2).

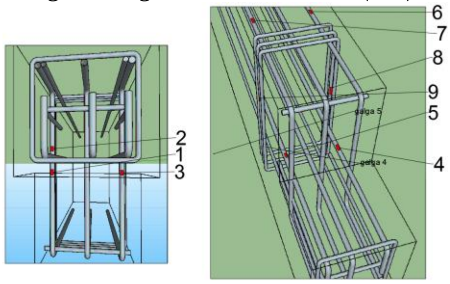


Fig. 6. Position of gauges in orthogonal reinforcement (M1).

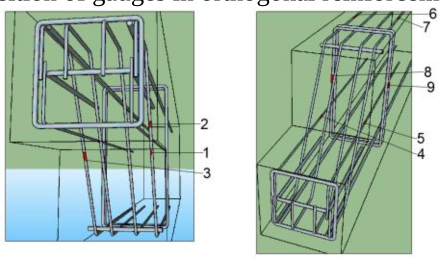


Fig. 7. Position of gauges in diagonal reinforcement (M2).

## III. RESULTS

The experiment was developed and a set of information was obtained that allowed identifying the elements that failed first. Table 1 shows the load at which the first element failed in M1, after 10 000 kg, the gauge that recorded the steel yield was the number 5 located in the main horizontal reinforcement steel in the nib, the gauge 4 that is located at the other end of the beam approaches the yield point.

Table 1. Steel stresses in M1.

| Load | Gauge No. | Strain | Stress (MPa) |
|---|---|---|---|
| 10 000 kg | 1 | 0.00089733 | 184.80 |
| | 2 | 0.00145176 | 298.97 |
| | 3 | 0.00121654 | 250.53 |
| | 4 | 0.00191927 | 395.25 |
| | 5 | 0.00207731 | 427.80 |
| | | | |
| | 6 | 0.00149026 | 306.90 |
| | 7 | 0.00184306 | 379.56 |

  

| | | | |
|---|---|---|---|
| | 8 | 0 | 0.00 |
| | 9 | 0 | 0.00 |

Table 2 contains the stress values that are presented in the steel of the element M2, the steel of the diagonal tensioner is the first that exceeds the yield strength, with the number 3 gauge registering the data at a load of 8500 kg.

Table 2. Steel stresses in M2.

| Load | Gauge No. | Strain | Stress (MPa) |
|---|---|---|---|
| | 1 | 0.000861073 | 173.02 |
| | 2 | 0.000745251 | 149.75 |
| | 3 | 0.002238713 | 449.84 |
| | 4 | 0.001177491 | 236.60 |
| 8 500 kg | 5 | 0.001171391 | 235.38 |
| | | | |
| | 6 | 0.00105808 | 212.61 |
| | 7 | 0.001414509 | 284.23 |
| | 8 | 0 | 0.00 |
| | 9 | 0 | 0.00 |

In fig. 8 presents the displacement that both elements obtained at the edge of the nib, it is observed that M2 take more load before starting to move, but from 7000 kg the distance is very similar.

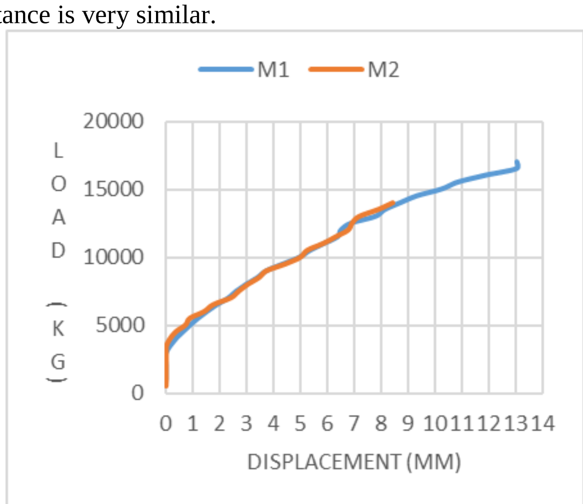


Fig. 8. Displacement of the end.

Table 3 presents the comparison of the results, contains the load obtained from the experiment and the design load of the two models, the efficiency approaches 1, M1 supported a 6% more load than the design while M2 supports 10 % more.

Table 3. Load comparison.

| | Experimental (kg) | Design (kg) | Efficiency |
|---|---|---|---|
| M1 | 16500 | 15500 | 1.06 |
| M2 | 17000 | 15500 | 1.10 |

## IV. CONCLUSIONS

From the work it is concluded that the diagonal MPT presents better behavior than the orthogonal MPT. The displacement is smaller in M2, the reinforcement stirrups in the entire section work until the concrete exceeds its shear strength.

Of the two models studied, the M2 transfers the load efficiently because the main tensor receives the load directly, and the capacity of the steel is used because it takes the direction of the stresses.

A diagonal MPT is an appropriate option, but it is necessary to study different load configurations.

ACKNOWLEDGMENT

The authors would like to thank the Program for Strengthening Educational Quality (PFCE-2016) for the support for the stay to make the manuscript.

## REFERENCES

[1] Rentería, J., Aguilera, E., & Dávalos, C. (2015). Ménsulas de extremo recortado en vigas de concreto. CULCyT, (55).
[2] ACI Committee 318, 2014, “Building Code Requirements for Structural Concrete (ACI 318S-14) and Commentary (318RS-14)”, American Concrete Institute, Farnibgton Hills, MI, 2014, 587 pp.
[3] Ritter, W., "The Hennebique Design Method (Die Bauweise Hennebique), Schweizerische Bauzeitung, (Zurich), V. 33, No. 7Feb. 1899, pp.59-61.
[4] Morsch, E., Concrete-Steel Construction (Der Eisenbetonbau), Translation of 3rd German Edition by E.P. Goodrich, McGraw-Hill Book Co., New York, 1909, 368 pp.
[5] Schlaich, J., Schafer, K. and Jnnewein, M. (1987), “Toward a consistent design of structural concrete”, Prestressed Concrete Institute Journal, 32(3), 74-150.
[6] Mattock, A. H., & Chan, T. C. (1979). Design and behavior of dapped-end beams. PCI Journal, 24(6), 28-45.
[7] Werner, M. P., & Dilger, W. H. (1973). Shear design of prestressed concrete stepped beams. PCI Journal, 18(4), 37-49.
[8] Cook, W. D., & Mitchell, D. (1988). Studies of disturbed regions near discontinuities in reinforced concrete members. Structural Journal, 85(2), 206-216.
[9] Wang, Q., Guo, Z., & Hoogenboom, P. C. (2005). Experimental investigation on the shear capacity of RC dapped end beams and design recommendations. Structural Engineering and Mechanics, 21(2), 221.
[10] Ley, M. T., Riding, K. A., Bae, S., & Breen, J. E. (2007). Experimental verification of strut-and-tie model design method. ACI Structural Journal, 104(6), 749-755.
[11] Mattock, A. H. (2012). Strut-and-Tie Models of Dapped-End Beams. Concrete International, 34(2).
[12] Mitchell D, Cook W. Design of disturbed regions. Stuttgart;1991.
[13] Ahmad, S., Elahi, A., Junaid Hafeez, M. F., &

  

Ahsan, Z. (2013). Evaluation of the shear strength of dapped ended beam. Life Science Journal, 10(3), 1038-1044.

[14] ASCE-ACI Committee 445. Recent Approaches to shear design of structural concrete. ACI Journal of Structural Engineering 1998:124(12):1375-1417.

[15] MacGregor, J.G. & Wight, J. K., (2012). “Reinforced concrete: mechanics and design.” Prentice Hall, 6th edition, Upper Saddle River, N.J., 1157 pages.

[16] Aswin, M., Syed, Z. I., Wee, T., & Liew, M. S. (2014). Prediction of Failure Loads of RC Dapped-End Beams. In Applied Mechanics and Materials (Vol. 567, pp. 463-468). Trans Tech Publications. https://doi.org/10.4028/www.scientific.net/AMM.567.463

[17] PCI Design Handbook, Precast/Prestressed Concrete Institute, 7th edition, 2010.

[18] BS 8110, Structural use of concrete-Part 1: Code of practice for design and construction, British Standards (BSi), (1997).

[19] Euro Code 2, Design of concrete structures-Part 1-1: General rules and rules for buildings, BS EN 1992-1-1: 2004, British Standards (BSi), (2004).

[20] Muhammad Aswin, Bashar S. Mohammed, M. S. Liew, and Zubair Imam Syed, “Shear Failure of RC Dapped-End Beams,” Advances in Materials Science and Engineering, vol. 2015, Article ID 309135, 11 pages, 2015. https://doi.org/10.1155/2015/309135.

[21] FIP Commission 3, 1998, “FIP Recommendation 1996, Practical Design of Structural Concrete,” Federation Internationale de la Precontrainte.

[22] 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. https://doi.org/10.1016/j.engstruct.2016.08.061.

  