STRUCTURAL CONFIGURATION OF ANCIENT FRAME STRUCTURES

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ABSTRACT

Upon seeing ancient monuments and how these structures remain in place throughout the years, it makes us wonder about the knowledge and the technology our ancestors had in ancient times. This report mainly discusses about the ancient stone frame structures consisting of stone columns and beams, built in the Anuradhapura era. In order to analyze these structures, modern theories which were developed in the 1700s by scientists like Euler and Bernoulli, were used (Flexure formula). The maximum tensile and compressive bending stresses for each beam, when subjected to a distributed load, were calculated. The stresses of the Stone Bridge were also analyzed when subjected to a distributed load as well as a point load. These calculations revealed that the beams were constructed in a way where they can uphold a maximum amount of load without reaching its maximum tensile stress value. We were able to see that the spans of the beams were limited to 2.4m. If the span of the beam exceeds this length there is a possibility for the beam to fail no matter how much the depth is increased. This shows us that the ancestors had an understanding about the maximum uniformly distributed load a beam can carry with respect to its span to depth ratio.

Keywords: Maximum Tensile Stress, Bending Moment, Stone

1. INTRODUCTION

Ancient structures, through the years, have been a reason for admiration. Upon seeing these monuments, we realize the great capacity of intelligence and wisdom that people had those days, where technology was limited, but not their goals. This is why these structures remain in place throughout the years.

This research is mainly focused on analyzing ancient stone frame structures consisting of stone columns and beams, built in the Anuradhapura era. For this purpose, stone frames selected were selected from Jethavana, Mahamewna and Abhayagiri premises. They are entrances of Gedige, Dhanashala, Dhalada Maligaawa, Awasa Mandapa and stone bridges. We were able to obtain a descriptive analysis of the structures, especially on beams made out of stone (granite).

Stone is the oldest construction material known to man. In the Anuradhapura era, it has been used as the most preferred material in construction of majority of ancient frame structures (ex. Lowa mahapaya. Rathna prasadaya). This could be, in fact, due to its unique qualities; i.e. aesthetics, permanence, accessibility and high compressive strength among others. Beams are generally subjected to tensile stresses whereas columns are normally subjected to compressive stresses. However, stone material is very weak in tension and therefore, the use of the span is limited. Therefore, we have mainly focused on analyzing beams of the structures in this particular research.

2. METHODOLOGY

In order to carry out this analysis, dimensions such as width, length and depth of the beams were measured. Then, the maximum tensile and compressive bending stresses for each beam, when subjected to a distributed load, were calculated using the Flexure Formula. The Stone

Bridge was also analyzed when subjected to a distributed load as well as a point load using the Flexure Formula.

2.1 Calculation of maximum tensile stress in beam under a Distributed Load

In order to estimate the strength of the beams when subjected to a distributed load, it is essential to identify the shape of the loading diagram for the distributed loads. The shape of the loading diagram depends on the arching action of the masonry above the opening. However, in this study, the shape of the loading diagram is assumed with the arching action. Therefore, it is reasonable to assume that the beam supports only the masonry that is contained within a triangle having sides which begin at the ends of the beams and slope upward and inward 45⁰ from the horizontal to converge at an apex above the beam, as shown in Figure1.

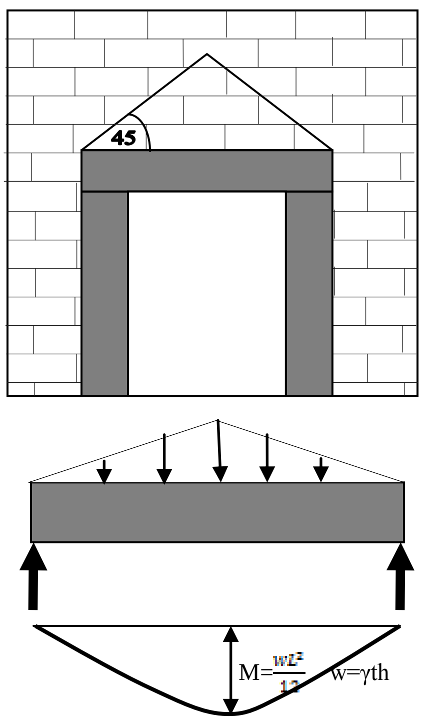

Figure 1: Bending moment distribution

Finally, the maximum tensile stress developed at the bottom of each beam is calculated using the Flexure Formula.

2.2 Calculation of maximum tensile stress in a beam under a Concentrated Load

Initially, the maximum bending moment was calculated assuming that the simply supported beam is subjected to a concentrated load at the middle of the beam as shown in Figure 2 and subsequently, the maximum tensile stress is calculated using the Flexure Formula.

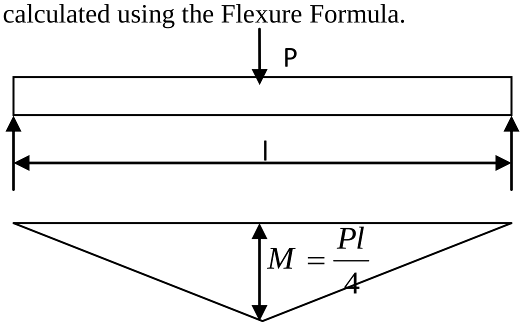

Figure 2: Bending moment distribution of a simply supported beam

3. RESULTS

Our calculations were executed mainly focusing on two main areas, as mentioned above. As an initial step, our data were summarized in a methodical manner as shown below. Then, the maximum uniformly distributed load a beam can carry, was calculated.

Table 1: Details of beams in stone frames

No	Span (m)	Depth (mm)	W (KN/m)	σ(MPa) at 45⁰
1	1.58	262.5	81.0	0.67
2	1.89	393.7	117.9	0.14
3	2.20	177.8	11.6	1.68
4	1.35	330.2	142.6	0.68
5	2.40	275.0	42.9	3.97
6	1.41	304.8	121.9	0.86
7	1.34	150.0	29.4	1.54
8	0.76	137.5	53.1	0.51
9	0.40	137.5	206.7	0.07
10	0.85	125.0	35.3	0.85
11	0.47	165.0	292.8	0.57
12	0.54	212.5	218.8	0.61
13	0.51	225.0	404.7	0.45

Table 1 indicates the dimensions, maximum uniformly distributed loads and maximum tensile stresses of the beams. First seven numbers represent the parameters of beams of the doors while the rest represent the parameters of the windows.

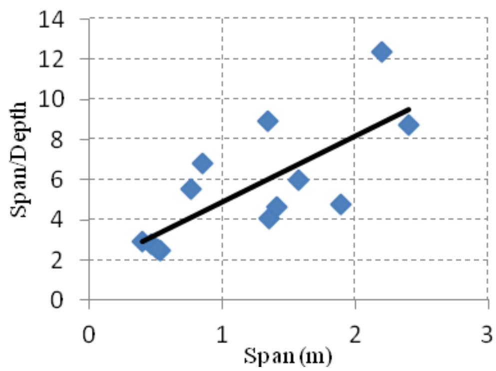

Figure 3: Variation of Span-to-depth ratio vs. span

Figure 3 clearly shows a relationship between span and span/depth ratio of the beams. After plotting the best suited curve, the linear relationship can be observed.

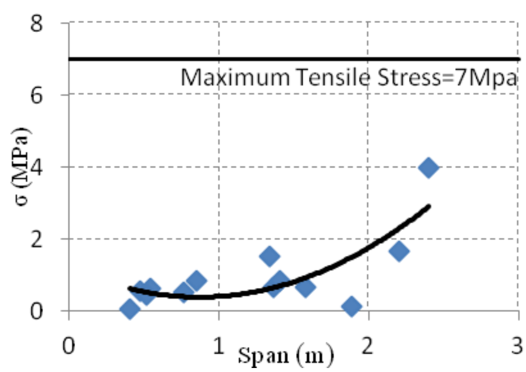

Figure 4: Variation of maximum tensile stress σ vs. span

Generally, in most beams, the maximum stress occurs, when a load corresponding to the area formed by an angle of 45°, is acting on the beam. But in this case, at an angle of 45°, all of these beams we analyzed take a stress value less than the ultimate tensile stress of the material (7MPa).

3.1 Stone bridge

In this section, initially we calculated the applied load assuming the weight of a fully loaded cart. The applied concentrated load acting on the stone bridge was 8.73kN while the stress due to the applied load was calculated to be 4.32MPa. The maximum tensile stress of the material takes a value of 7MPa. Therefore, the maximum load that can be applied to the beam was found to be 14.132kN. The maximum bearing load (14.132kN) of the bridge takes a value which is greater than the applied load (8.73kN). Therefore the design criterion of the bridge is satisfied.

4. CONCLUSION

By the observation of Figure 3, it is observed that our ancestors had a clear idea about the span depth ratio and how the depth should be varied along with the length of the span. Figure 4 clearly shows us that they carried out a certain methodology understanding the maximum uniformly distributed load a beam can carry with respect to its length. The calculated data also revealed us that when selecting beams for entrances, our ancestors had a clear idea about the load which the beam gets from the wall and up to what angle this load should be resisted. And also, calculated values show that stone bridges in ancient times were created to withstand a weight of a fully loaded cart.

Looking at these structures and how they remain in place to this date proves to us that our ancestors had sufficient knowledge on technology, to build a variety of structures. By collecting sufficient data and analyzing these structures using modern theories, we were able to prove that our ancestors had a clear idea on what they were doing in building these structures. This indicates how aware the ancestors were about the load distribution in beams and also, how precisely they have chosen the spans of each beam.

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