BEHAVIOUR OF LATERIZED CONCRETE BEAMS UNDER MOMENT AND SHEAR

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(Accepted for publication on 21st February, 1991)

ABSTRACT

The science and technique of substituting laterite for fine aggregate in normal concrete work is rapidly increasing in Nigeria. Studies on laterized concrete elements have been devoted primarily to observation under unit actions like the cube strength, split tensile strength, modulus of rupture and creep characteristics. The present report gives the results of twenty four reinforced-laterized concrete beams, they were tested under combined actions of moment and shear. The principal variable are the mix proportions, percentage tensile reinforcement and shear span to effective depth ratio (ad). The results showed that the higher the percentage tensile reinforcement and cement/aggregate ratio the higher the shear and moment capacities of the beams. When the shear span to effective depth ratio was increased, the shear capacity of the beams decreased while moment capacity increased. The shear span to effective depth ratio is the single most important factor that influences the mode of failure of the laterized concrete beams.

1. INTRODUCTION

The basic and most utilised construction materials in building industry are the fine and coarse aggregates and cement as components in concrete. Over the years, the availability of these materials has not been sufficient to meet the demand of the industry especially the fine aggregate in building industry are the fine and coarse aggregates and cement produced. The high cost of the fine aggregate (sand) is second most expensive item per unit volume of concrete. The common sources, it may need additional treatment such as washing to remove some undesirable chemical substances and other organic matters like humus that may be present. A possible remedy to this will be to replace the sand with suitable lateritic soils in the production of concrete. These soils, apart from being tropical in origin, are readily available in many less developed countries where they can be simply collected from locations adjacent to the construction sites, and this indeed is a great advantage since speedier procurement significantly curtails construction time. The aim of this study is to investigate the behaviour of laterized concrete beams under moment and shear.

2. PREVIOUS WORK

In Nigeria, lateritic soils are readily available but they lack credibility as construction materials because of inadequate knowledge about their engineering properties. Researchers are making efforts to define these properties to enhance their efficient utilisation. Gidigasu (1976) defined laterite as all the reddish residual and non-residual tropically weathered soils, which genetically form a chain of materials ranging from decomposed rock crusts, generally known as Chirasscon Carrapae. Investigations by Lasisi and Osunade (1984) showed that the finer the grain sizes of lateritic soils, the higher the compressive strength obtained. A study by Adepegba (1975), in which the strength properties of normal concrete were compared with those of laterized concrete concluded that a concrete in which lateritic fines are used instead of sand can be used as a structural material in place of normal concrete. In a study by Balogun and Adepegba (1982), it was reported that when sand is mixed with lateritic fines the most suitable mix for structural application is 1:3 with a water/cement ratio of 0.65 provided that the laterite content is kept below 50 percent. It has been reported by Ola (1983) that lateritic soils can be effectively stabilised with less than 50 percent of the cement that is required for subgrade works in which temperature zones soils are used. In another study by Lasisi (1977), it was found that lateritic soils could be used for producing masonry blocks when stabilized with about 10 percent cement. It was reported by Lasisi and Ogunjide (1984), that below 30 percent cement stabilisation, all grain size ranges exhibit decreasing strength with age. According to these findings, grain size separation may not be an effective way to improve the strength characteristics of lateritic soils. Mesida (1978) has reported that lateritic soils in Okitipupa area of Ondo State of Nigeria need only 10-12 percent cement for stabilisation to become reliable for building purposes in that area. Lasisi, et al. (1984) worked on factors affecting the strength of laterite/cement mortars. It was reported that clay impairs the strength of lateritic-cement mortars, and that for some mix proportions, the strength compares favourably with that for sand-cement mortars. It was also found that laterite-cement mortars could be designed for strength ranging from below
1N/mm² to about 30N/mm². Studies by Madu (1976, 1980) indicated that some Eastern Nigeria lateritic aggregates are good materials for the road chippings and concrete aggregates but with slightly inferior results to those obtained from igneous aggregates.

3. MATERIALS AND EXPERIMENTAL PROCEDURE

Soil Sample Collection

The lateritic soil sample used for this experiment was collected from kilometer 10, Ifewara Road, Ile-Ife. The coarse aggregates were from crushed granite origin. The range of the size is 10-19mm (see Fig. 1).

![Sieve Analysis of Lateritic Soil](image)

Fig. 1. Results of sieve analysis of the lateritic soil sample and crushed aggregate.

Grain Size Selection

Sieve analysis of the lateritic soil sample was carried out (Fig. 1). The lateritic fines were obtained by removing the soil sample retained on sieve No. 8 (aperture 2.36mm) and soil passing through sieve No. 50 (aperture 0.30mm) thus making use of those retained on aperture 0.30mm and passing through aperture 2.36mm. The uniformity coefficient (U) of the sample used was 6.75 and the coefficient of curvature (C) was 1.33. These showed that the lateritic soil sample used was well graded (U>5 and 1.5<C<3) (Terzaghi and Peck, 1967).

Mix Proportion Selection

Two different mixes of cement, lateritic soil and coarse aggregate were used namely 1:1:2 with water/cement ratio of 0.494 by weight and 1:2:4 with water/cement ratio of 0.753 representing a rich mix (aggregate/cement ratio between 3 and 5) and an ordinary mix (aggregate/cement ratio between 6 and 9). The water/cement ratio was determined using the relationship established by Lasisi and Ogunjimi (1984) (See Fig. 2). Four different percentages of tensile reinforcement were considered (Clauses 3.11.4.1 and 3.11.5 of CP110, 1972). Based on these clauses, a number of the readily available bar sizes (M6, M8, M10 and M12) were chosen. The area of each bar group was expressed as a percentage of the gross sectional area of the laterized concrete beam. These percentages were found to be 0.38, 0.67, 1.05 and 1.51% for 2M6, 2M8, 2M10 and 2M12 respectively. The beams were singly reinforced and the bars were fully anchored. The reinforcement material used was mild steel bars of characteristic yield stress of 250N/mm².

Specimen Moulding

Two types of moulds were used: 100x150x2000mm wooden moulds for the beam specimens and 100x100x100mm metal moulds for the cube specimens. The different mixtures of cement lateritic soil and crushed stone were worked manually. The addition of water to each mix was done gradually and in stages and well spread throughout the surface of the mix to avoid the formation of stiff paste balls of lateritic soils. The paste was thoroughly mixed until the consistency and colour were uniform. The cube specimens were made by filling each mould in three layers, each layer having been computed manually with 25 blows from a steel rod of 25mm diameter before the next layer was poured. All the beams were singly reinforced with 25mm cover to the reinforcing bars from the tension face. The average effective depth was found to be 120mm. This gave the values of shear span 240mm for a/d=2, 540mm and 720mm for a/d=4.5 and 6 respectively (Table 1). Moist curing was adopted for the
specimens. The beams and the cube specimens were covered with jute bags and wetted twice daily to maintain adequate moisture necessary for the hydration process of the landcrete. The beams were tested for combined moment and shear under two point loading with varying shear span to effective depth ratios (see Fig. 3). Three different shear span to effective depth ratios (2, 4.5 and 6) were considered (Niyogi and Dwarakanathun, 1985).

Fig. 3: Details of reinforcement for beams under bending and shear.

For each a/d, four beams were moulded for each mix proportion making a total of eight beams for each shear span to effective depth ratio and overall number of 24 beams. A loading rate of 120KN per minute was adopted on ELE Beam testing machine.

4. RESULTS AND DISCUSSION

The test beams were 100x150mm deep and 2000mm in overall length. They were analysed as simply supported beams over a span of 1800mm. The constant moment zone was tested for combined bending and shear. The compressive strength results on the cube specimens at 28 day curing were 23N/mm$^2$ for 1:1:2 and 17N/mm$^2$ for 1:2:4 mixes. The values of ultimate shear force observed at failure sections of the beam and bending moment are presented in Tables 1 and 2. The tables show that the shear span/effective depth ratio has great influence on the strengths of the beams. When the shear span/effective depth ratio was increased the shear capacity of the beams decreased while the moment capacity increased. Fig. 4 for 1:2:4 mix shows that at 0.38% tensile reinforcement and a/d=2 the ultimate shear force is 0.51N/mm$^2$, for a/d=4.5 and a/d=6 the values are 0.41N/mm$^2$ and 0.33N/mm$^2$ for the same mix. Table 2 shows that the moment values are 1.49kN.m, 2.67kN.m and 2.92kN.m for a/d=2, a/d=4.5 and a/d=6 for the same mix and percentage tensile reinforcement. The same trend of reduced shear strength and increased moment capacity was noticed in 1:1:2 mix. Fig. 5 for 1:1:2 mix shows that the ultimate shear stress at failure as a function of the shear span to effective depth ratio for 1:2:4 mix shear stress values are 0.75N/mm$^2$, 0.54N/mm$^2$ and 0.47N/mm$^2$ for a/d=2, a/d=4.5 and a/d=6 at 0.38% tensile reinforcement while the moment values are 2.18kN.m, 3.56kN.m and 4.14kN.m respectively.

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<th>V0(kN)</th>
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<th>V0(kN)</th>
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*Concrete in which the sand is replaced with lateritic fines.
Fig. 4: Shear stress at failure as a function of the shear span to effective depth ratio for 1:2:4 mix.

The decrease in shear strength can be attributed to the fact that in beams with only tensile reinforcement, the resistance to shear is provided by the combination of a shear force across the compression zone, a dowel force transmitted across the crack by flexural reinforcement and the vertical components of inclined crack by means of interlocking of the aggregate particles. However, in the case under consideration when the shear span/effective depth ratio was increased, the line of action of the applied external concentrated load increased from the support. This enabled the load to weaken the bond between the concrete and the reinforcement thus giving rise to inclined cracks. When shear displacement occurred along the crack, certain amount of shear was transferred by means of the dowel action of the flexural reinforcement. But because the bars bore against the cover concrete, the dowel capacity was limited by the tensile strength of concrete. Once a splitting crack occurred, the stiffness, hence the effectiveness, of the dowel action greatly reduced. The splitting also adversely affected the bond performance of the bar. These resulted in the reduction of the overall shear capacity of the beams but moment of resistance of a beam, which is the product of the external force and the lever arm, increased as the shear span/effective depth ratio increased hence the values of bending moment increased.

Fig. 5: Shear stress at failure as a function of the shear span to effective depth ratio for 1:1:2 mix.

The results also showed that the higher the percentage of tensile reinforcement the higher the strengths of the beams (see Fig. 6). The increase in strength was due to the fact that when the percentage tensile reinforcement was increased in the shear span, narrower flexural cracks were observed. This resulted in increase of the depth of the uncracked compression concrete, which enabled the aggregate interlock and dowel actions to carry large load and this improved the shear resistance of the beam. Table 2 shows that the ultimate shear resistance also increased for concrete.
0·35
0·30
----1:1:2 Mix
- - - -1:2:4 Mix
x = a/d = 2
○ = a/d = 4.5
• = a/d = 6

Fig. 6: Relationship between shear capacity and percentage tensile reinforcement.

with low aggregate/cement ratio. For example, 1:1:2 mix at 0.67% tensile reinforcement and shear span/effective depth ratio a/d=2, the ultimate shear stresses were 1.20N/mm² and 0.72N/mm² for 1:2:4 mix. This can be attributed to the large quantity of cement in 1:1:2 (aggregate/cement = 3). High cement content increases the bond performance of the reinforcement with the concrete thus improving the load carrying capacity of the beam. The reduced strength in 1:2:4 was due to high aggregate/ cement ratio (aggregate/cement = 6). The cement content is also responsible for higher compressive strength of 23N/mm² obtained for 1:1:2 and a lower value of 17N/mm² in 1:2:4 mix. The strength values in Table 2 show that the effect of varying shear span/effective depth ratio is more pronounced with concrete with low aggregate/cement ratio. For 1:1:2 at 0.38% tensile reinforcement and a/d=2, the ultimate shear stress = 0.75N/mm², for a/d=4.5 the shear stress = 0.54N/mm² (28% reduction) and for a/d=6, the shear stress = 0.47N/mm² (37% reduction) but for 1:2:4 at the same percentage tensile reinforcement the results were for a/d=2, the shear stress = 0.51N/mm², for a/d=4.5 and a/d=6 the shear values were 0.41N/mm² (20% reduction) and 0.35N/mm² (35% reduction) respectively.

Fig. 7(a-c) shows the failure mechanism of beam specimens under the combined action of bending and shear. Reinforced laterized concrete beams under combined bending and shear exhibited two distinct failure modes, one of typical shear and the other of bending. For small shear span/effective depth ratio (a/d=2) an arch action was observed which represents the behaviour of short deep beams or beams with load applied to the compression zone close to the support as is the case under consideration. Most of the vertical load is transmitted to the supports by arch action. This action occurs when the bond between steel and concrete has been destroyed over the entire length of the shear span, under such circumstances the external shear is resisted only by internal compression force. Shear stress and interface shear transfer along the crack are not as important as in slender beams. Failure occurs along the main bar.

Fig. 7: Typical Crack patterns for Beam under combined bending and shear.
(a) a/d=2; (b) a/d=4.5; (c) a/d=6.
tension cracking thus causing the compression side to be overstressed due to the increasing shear and compression force the zone has to sustain and this leads to shear compression failure. When a/d = 6, the specimens exhibited flexural tensile failures. The crack is perpendicular to the centroidal axis of the beam. At the failure zone, the effect of the bending moment is much higher than the shear force and this is why the flexural tensile failure predominates.

5. CONCLUSIONS

Within the scope of the present investigation, the following conclusions can be made:

(i) For the same percentage tensile reinforcement and manner of loading, beams of high aggregate/cement ratio (1:2:4) as compared with those of low aggregate/cement ratio (1:1:2) generally have lower strengths.

(ii) As the shear span to effective depth ratio increased the shear capacity of laterized concrete beams decreased while the moment capacity increased.

(iii) As the percentage tensile reinforcement increased, the shear and moment capacities increased for both mixes considered.

(iv) The shear span to effective depth ratio influenced the combined effects of shear and moment capacities and dictated the mode of failure of the laterised concrete beams.

(v) The closer external loads were applied to the beam supports the higher the shear resistance but the lower the moment capacity of the beam.

6. NOTATIONS

a  shear span (mm)
b  width of the beam (mm)
d  effective depth (mm)
A_r  area of reinforcement (mm²)
R_t  tensile reinforcement (%)\nV_s  ultimate shear force, kN
M_u  ultimate moment, kNm
M  mild steel reinforcement
f_{cm}  28th day compressive strength of laterite cubes.

REFERENCES


