STRUCTURAL PERFORMANCE OF MANGROVE REINFORCED CONCRETE BEAMS

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ABSTRACT

This study evaluates the potential to utilize mangrove as reinforcement in concrete structural members. Preliminary tests on tensile strength of mangrove bars was done and compared to that of steel applied as reinforcement in the control beam to establish individual material strengths. Further, flexural test on mangrove reinforced beams was conducted and characterized by comparing with the control steel reinforced concrete beams. Singly and doubly mangrove reinforced beams of1100mm length having 150mm width and 250mmdepthwere tested in flexure and compared with steel reinforced concrete control beams. Three variables diameters of 30mm, 25mm and 20mm of mangrove bars were used for the beam specimens made from concrete with an average strength of 19.3 N/mm². The control beams were reinforced with standard 10mm steel bar. The test results showed that even though mangrove had lower tensile strength as compared to steel, flexural tests results showed that beam of 7.8 % reinforcement ratio of mangrove had higher ultimate load as compared to that of the control beams.

KEYWORDS: *Mangrove Reinforcement, Tensile Strength, Flexural Strength, Deflection*

I. INTRODUCTION

Generally concrete as a widely used construction material has relatively high compressive strength and is used largely because it is economical, has good fire resistance and is a readily available material. Since, concrete is weak in tension it is necessary to reinforce it with some other materials to strengthen it in tension. One of the more popular reinforcing bars (rebar) for concrete is steel. Steel has a relatively high tensile strength and is used to complement the low tensile strength of concrete. Although it is available and affordable in developed countries it is still considered an expensive construction material in most of the developing countries. Availability of construction material in a near vicinity and use of locally produced material saves a lot on construction cost and also in terms of energy [1]. There exists a need for more economical and readily available substitute reinforcements for concrete. Moreover, the increase in the cost and general shortage of reinforcing steel recently in many parts of the world particularly in Africa has led to increasing interest in the possible use of alternative locally available materials for the reinforcement of concrete such as Mangrove poles, bamboo, etc. In Nigeria and other developing countries, the cost of steel has limited the proportion of citizens who can afford their own house to about 30% [2].This study therefore has conducted a study on the technical capabilities of mangrove of genus Rhizophora as reinforcement in the concrete.

Despite the lack of information on the technical capabilities, Mangrove poles have been used in Kenya and some of the devolving countries in composite structures (i.e. structures framed using mangrove poles in conjunction with other building materials. They have been used as reinforcement for structural elements for a long period since fifteenth century. It has been applied as reinforcement

for floor slabs and beam elements consisting of coral rag prepared from lime mortar mixed with coral aggregate/hardcore and some soil [3].
This paper, experimental investigation and evaluation of the use of mangrove as reinforcing bar in concrete as a replacement for steel is presented.

II. MATERIALS PROPERTIES

2.1 Coarse Aggregate

The selection and specification of coarse aggregate in this research was made in accordance with BS 882 [4]. Crushed stone with a maximum size of 20mm was used as coarse aggregates in beam samples. Specific gravity and absorption characteristics of the coarse aggregate used were determined in accordance to ASTM C 127 [5] and the values are given in Table 1.

2.2 Fine Aggregate

River sand whose similar material properties (Table 1) as that of coarse aggregates were determined in accordance to ASTM C 128 [6] was used and the values are given in Table 1.

Table 1: Results of Specific Gravity and Absorption of Aggregates

Designation	Bulk Specific Gravity (oven-dry)	Bulk Specific Gravity (SSD)	Apparent Specific Gravity	Absorption in Percent
Coarse aggregate, Maximum size 20 mm	2.7	2.8	3.0	3.4
Fine aggregate	2.5	2.6	2.6	1.0

2.3 Mangrove

The species of mangrove poles used in this research were sourced from Mwtapa, along the Kenya coast. Harvested mangrove poles with age range between 15 to 25 years were selected. For their use as reinforcements in beams, the poles were first shaped into round bar shapes. The following criteria were considered in the selection of mangrove poles for use as reinforcement in concrete: (a) use of a mature plant with no voids in the middle trunk (b) minimal defects where possible (c) seasoned mangrove.

III. SAMPLE PREPARATION

3.1 Mangrove Poles

The mangrove poles selected were those already dried and their application did not require further moisture reduction processed. Once they were shaped approximately to the sizes required, their diameters were measured at seven marked points distant of 170 mm from one another with a caliper along the length of the mangrove poles and then the average of the values measured from each mangrove was determined as the designated respective diameter. In order to conduct the tensile strength test, it was necessary to prepare the mangrove sample as referred to in BS 373 [7].

3.2 Concrete Mix Design

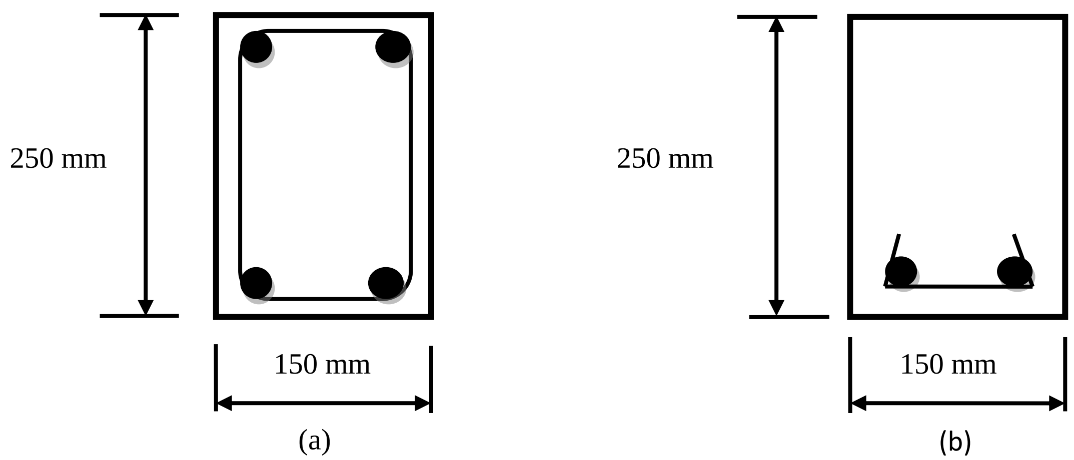
The concrete used for casting the beams was made using Portland Pozzolana Cement as per Kenya Standards, crushed stone with triangular shape as coarse aggregate with a maximum size of 20 mm, and natural sand supplied from one of the local rivers as fine aggregate. The mixes were designed for 28 days cylinder strength of 20 N/mm² with a water-cement ratio 0.5. The concrete mix proportions was 1:1.75:2 (cement: fine aggregate: coarse aggregate) with a slump value of 50 ± 5 mm to ensure consistency of the concrete mix.

3.3 Beam Specimens

In this research, two types of beam reinforcement mode were used according to the number of reinforcements namely: (a) singly reinforced beam and (b) doubly reinforced beam. Shear reinforcement, 6 mm diameter mild steel was provided at 170 mm centre-to-centre spacing throughout the length of the beam. Details of diameters of reinforcement and reinforcement ratio are given in Table 2.

All beams in this research were cast from one batch of concrete. Reinforcements were well positioned by the use of 20 mm thick concrete spacer blocks tied under the reinforcements of the tension zone in contact of the bottoms of formworks and laterally between the reinforcements and lateral part of the formworks to control the clear cover during casting. Concrete was then placed into the formworks and around the mangrove or steel reinforcements. A poker vibrator was used to compact the concrete and ensure there was homogeneity. When all the concrete was added to the formworks, the tops were made smooth with a trowel. The specimens were demoulded after 24 hours and were cured for 28days where they were continuously kept under wet conditions. Cylindrical 100 mm diameter and 200 mm height Compressive and tensile strength specimens were also cast from the same concrete mix and demoulded after 24 hours and cured by in a water tank for 28days.Figure 1shows the transverse cross section of different types of the beam samples. For ease of beam specimen description, the following notations were applied and are used throughout this paper:

BR4MPΦ30: Beam Reinforced with Four Mangrove Poles of 30 mm of Diameter.
BR4MPΦ25: Beam Reinforced with Four Mangrove Poles of 25 mm of Diameter.
BR4MPΦ20: Beam Reinforced with Four Mangrove Poles of 20 mm of Diameter.
BR4SBΦ10: Beam Reinforced with Four Steel Bars of 10 mm of Diameter.
BR2MPΦ30: Beam Reinforced with Two Mangrove Poles of 30 mm of Diameter.
BR2MPΦ25: Beam Reinforced with Two Mangrove Poles of 25 mm of Diameter.
BR2MPΦ20: Beam Reinforced with Two Mangrove Poles of 20 mm of Diameter.



(a) Doubly Reinforced: case of BR4MPΦ30, BR4MPΦ25, BR4MPΦ20 and BR4SBΦ12
(b) Singly Reinforced: case of BR2MPΦ30, BR2MPΦ25 and BR2MPΦ20

Figure 1: Cross-Section of Sample Concrete Beam

IV. Experimental Program

The experimental program entailed determination of compressive and tensile strength of cylinders, tensile strengths of mangrove and steel bars and flexural strength of the mangrove and steel reinforced concrete Beams. The testing procedures are as summarized in the section below.

4.1 Tensile Strength Test of Steel

Three specimens were prepared suitably for gripping in the testing machine. The specimens used were approximately uniform over a gage length (the length within which elongation measurements are done**).** The steel used was of 10 mm diameter with original length of 500 mm. Before the test commences, gauge length was marked, the weight of specimen measured. During testing, the specimens were tensioned gradually until rupture. Elongation was measured at regular interval of applied tensile load. During the applying tensile load (as pulling proceeds), the change in the gauge length of the sample is measured from a sensor attached to the sample (extensometer).

4.2 Tensile Strength Test of Mangrove

The resistance to tension of mangrove was determined parallel to the grain. The test piece was so orientated that the direction of the annual rings at the cuboidal section was perpendicular to the greater cross-sectional dimensions. Actual dimensions at the minimum cross-section were measured. The load was applied to the 2 cm face of the ends of the test piece by special toothed plate grips which were forced into the wood before the test piece commenced as shown in Figure 2. These grips were designed so as to give axial load. The load was applied to the test piece at a constant head speed of 0.05 in./min.

Figure 2: Tension Parallel to Grain test of Mangrove

4.3 Flexural Test of Beam, Compressive and Tensile Test of Cylinder

Flexural testing was conducted based on a three point bending loading arrangement as shown in Figure 3.The beam was picked up with the forklift and carefully placed between the upper and the lower frames of the Universal Testing Machine on the supports at the measured location of 900 mm inside from center to center of the supports as shown in Figure 4. Displacement Transducer was also installed at midspan to measure the deflection. Loading was applied gradually at the midspan of the beam specimen to failure. The deflection of the beam at midspan was measured at regular interval of loading. Figure 4 illustrates the test setup.

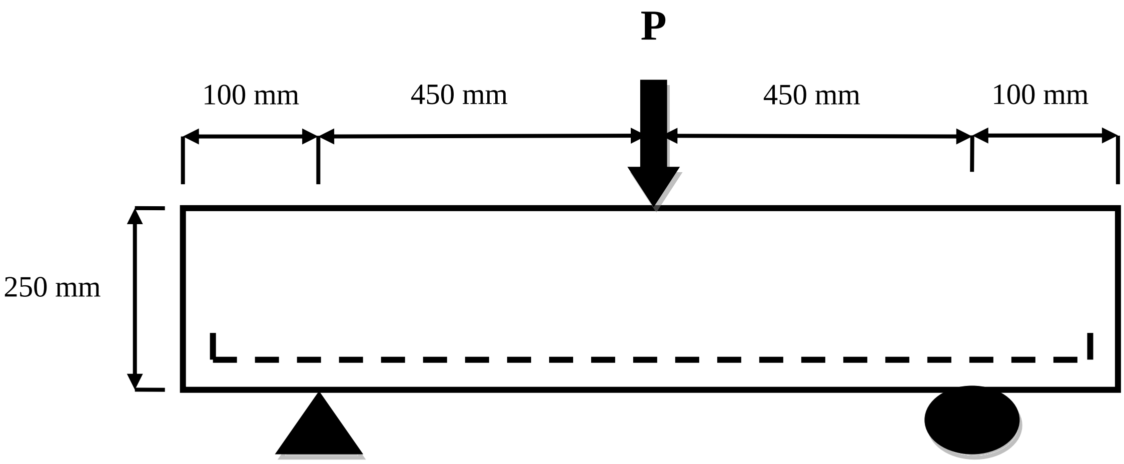


Figure 3: Three Point Bending Test Set Up

Compressive and tensile strength tests of cylindrical concrete were performed and the average 28 day respective strengths were determined.

V. RESULTS AND DISCUSSIONS

5.1 Tensile Strength of Steel

The results of tensile strength of steel of 10 mm of diameter used for the beam as control was about 447 N/mm^2, which is established to be slightly lower than the specified strength for high yield steel strength as provided for in the standards as approximately 460 N/mm^2. None the less the objective of the test was to establish the steel tensile strength as used in the control beams to allow for comparisons with that of mangrove as discussed in the section below.

5.2 Tensile Strength of Mangrove

During these tensile tests, all tensile specimens' failure occurred near the edge prepared for the grip. The stresses of the mangrove specimens found are quite different from one another since mangrove is a natural material and the defects (knot size, slope, splits, etc) that they have in them vary from one another. Taking the defects into account, average stress has been reduced by a safety factor of 0.8 which is the coefficient of safety of wood as provided for in BS 5268 [8] to obtain the characteristic tensile strength approximately equal to 153 N/mm^2. It is noted that the tensile strength of mangrove as compared with that is approximately three times less than that of steel. None the less, its usage may still be applicable particularly where loadings regimes can be accommodated within the mangrove strength.

5.3 Compressive and Tensile Strength of Cylinder

Average compressive strength of concrete cylindrical test of 100 mm diameter and 200 mm height for 28 days was 19.3 N/mm^2, while the average tensile strength was established to be 2.3 N/mm^2.

5.4 Flexural Strength of Beam

Comparison of the flexural behavior of mangrove reinforced concrete beams and steel reinforced control concrete beam is as shown in Figures 4 and 5. From the results, it is noted that mangrove concrete beams reinforced with larger diameter of mangrove poles (BR4MPΦ30C20) showed slightly higher ultimate load of 82kN but with a lower deflection of 7mm. This is higher than that of the control steel reinforced beam (BR4SBΦ10C20) which had ultimate strength of 75kN and a deflection of 15mm. A review of the other mangrove reinforced beams reinforced with smaller diameters of mangrove poles show lower ultimate load at failure with a corresponding much lower deflection levels. One common characteristic of the mangrove reinforced concrete beams is that even though the physical failure mode (see Figure 6and 7) shows flexure and combined flexure and shear failure mode, the results shown in Figure 4 and 5indicate a more semi-brittle failure as compared to the control beam. The brittle failure in the mangrove beams that exhibited flexural cracking but with sudden failure may be attributed to the existence of defects such as Knots in the poles. Obviously steel reinforced control beam exhibited a more ductile characteristic due to the intrinsic elastic properties of steel. It is evident that the load carrying capacity and deflection capacity depends on the reinforcement ratio of the mangrove: the higher the reinforcement ratio of the mangrove, the higher the load carrying and deflection capacity. As illustrated by the doted lines, the Figures also indicate a lower elastic stiffness of the mangrove reinforced beams as compared to that of the control steel beam attributable to the lower modulus of elasticity of mangrove poles. However, the post-elastic stiffness of mangrove reinforced beams seems to be higher than that of steel reinforced beams.

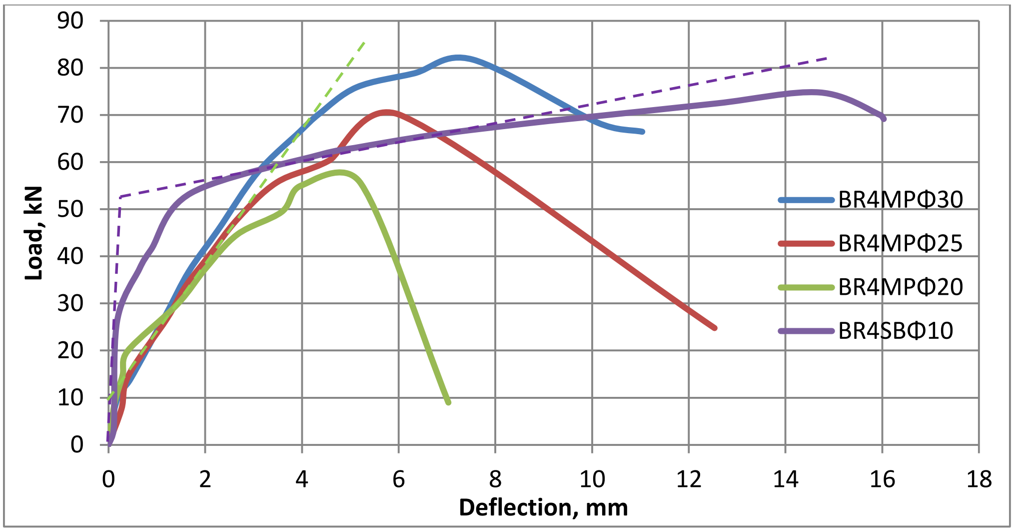


Figure 4: Load-Deflection Curve for Doubly Mangrove Reinforced Beam

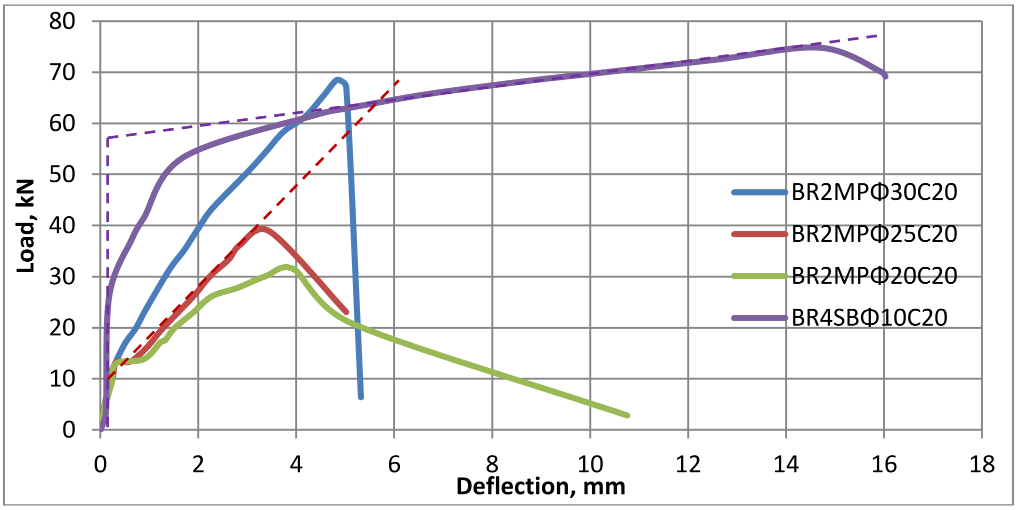


Figure 5: Load-Deflection Curve for Singly Mangrove Reinforced Beam

6.1 Failure Pattern of BR4MPΦ30

6.2 Failure Pattern of BR4MPΦ25

6.3 Failure Pattern of BR4MPΦ20

6.4 Failure Pattern of BR2MPΦ30

6.5 Failure Pattern of BR4MPΦ25

6.6 Failure Mode of BR4MPΦ20

Figure 6: Failure Pattern of Beams

Figure 7: Failure Pattern of BR4SBΦ10 (Control Beam)

Figure 8: Crack of Mangrove Pole inside the Beam

Table 2 shows the reinforcement ratio, the cracking load and its moment, the ultimate load carrying capacity and its moment and the maximum deflection of singly reinforced beam and doubly reinforced beam at 28 days.

Table 2: Summary of Beams Results

Specimen	Reinforcement ration (ρ) in %	Load at crack (Pcr) in kN	Moment at crack (Mcr) in kNm	Max. load (Pmax) in kN	Deflection at Max. load (δu) in mm	Max. moment (Mu) in kNm	Failure Mode
BR4MPΦ30	7.8	11	2.48	82	7.5	18.5	Flexure + Shear
BR4MPΦ25	5.3	15	3.4	70	6.1	15.8	Flexure + Shear
BR4MPΦ20	3.4	20	4.5	55	5.2	12.4	Flexure + Shear
BR4SBΦ10	0.8	41	9.2	75	14.7	16.9	Flexure
BR2MPΦ30	3.9	17	3.8	69	4.8	15.5	Flexure
BR2MPΦ25	2.5	16	3.6	39	3.5	8.8	Flexure
BR4MPΦ20	1.7	14	3.2	31	4.0	7.0	Flexure

5.5 Beam Failure Modes

The test results from Table 2 shows that the beams with 7.80% mangrove reinforcement ratio (BR4MPΦ30) failed in flexure accompanied by more shear cracks near the support on the left side as seen in Figure 6.1. This could be as a result of a higher reinforcement ratio and thus ability to carry more load than the other beams including the control beams. Beams BR4MPΦ25 and BR4MPΦ20 failed in bending accompanied by one shear crack near the support on the right side as shown in Figure 6.2 and 3 respectively. These two beams (BR4MPΦ25 and BR4MPΦ20) had almost the same failure mode; the only difference is that the first bending crack of BR4MPΦ25 did not occur exactly at the center of the beam but a bit more to the left giving way to a second crack opposing it to the right near the center as well (see Figure 6.2).While the first crack of BR4MPΦ20 occurred at the center of the beam and vertically from the bottom to the top as shown in Figure 6.3,BR2MPΦ30 failed in bending by a central vertical crack accompanied by small cracks both on the left and right side of the beam as shown in Figure 6.4. It is noted in Figure 6.4 that a piece of concrete fell out from the lower section of the beam, revealing a nearly perfect imprint of the mangrove reinforcement. This suggested a poor bonding between the concrete and mangrove, leading to bond failure. Upon examining the beam at the region of failure crack (Figure 8) the mangrove pole in tension seemed to be broken, leading to the assumption that the beam failed in due to existence of Knot defect. However, failure pattern of BR2MPΦ25 and BR2MPΦ20 are similar, both of them failed in bending by only one vertical crack more or less at the center from the bottom to the top of the beam. While BR4SBΦ10 failed in bending with high ductility. During test, two vertical cracks occurred on BR4SBΦ10 equidistant from each other from the center as shown in Figure 7.

It was noted that during testing all the beams reinforced with mangrove poles failed suddenly accompanied by a loud deep sound due to mangrove cracking and failed at the maximum load, while the beam reinforced with steel shows a ductile failure behavior.

VI. CONCLUSIONS

This investigation provided an insight on the technical capabilities of mangrove as a potential reinforcement in concrete for structural use. More specifically;

(a) It is determined from material property tests that mangrove poles possess low tensile strength as compared to that of steel.

(b) But from the flexural test on mangrove reinforced beams demonstrate that using mangrove as reinforcement in concrete can increases the load carrying capacity of reinforced concrete beam having the same dimensions. For doubly mangrove reinforced concrete beams, the load carrying capacity increased by about 1.6 times than that of singly mangrove reinforced concrete beam having same dimensions.

(c) Flexural test results further shown that the maximum deflection of doubly reinforced beam is about 1.5 times than that of singly reinforced beam. However, mangrove can not be utilized in heavily loaded structural elements which ordinarily would use steel of larger ratio. Applicability of mangrove would be more in less loaded structural elements such as in beams such as those found in load bearing structural walls.

(d) It is also determined that the sizes and the number of cracks vary according the sizes of the reinforcements or reinforcement ratio: the bigger the reinforcement ratio of the mangrove poles the bigger and numerous the cracks appeared on the beam, the smaller the reinforcement ratio of the mangrove poles the lesser and smaller the cracks appeared on the beam.

REFERENCES

[1] Pawar, S. (2014). Bamboo in Construction Technology. Research India Publications, 4 (4), 347-352.

[2] Musbau, A., Ismail, A., & Efe, E. (2012). Characteristic Strength of Concrete column Reinforced with Bamboo Strips. Journal of Sustainable Development , 5, 133-143.

[3] Manguriu, G., Oyawa, W., & Abuodha, S. (2013). Physical and mechanical properties of mangrove from Kilifi in Kenya. Global Engineers & Technologists Review , 3, 1-5.

[4] BS 882. (1992). Specification for aggregates from natural sources for concrete. UK, London.

[5] ASTM C 127. (2000). Specific gravity and absorption tests of coarse aggregate. United States of America.

[6] ASTM C 128. (2000). Specific gravity and absorption tests of fine aggregate. United States of America.

[7] BS 373. (1957). Methods of testing small clear specimens of timber. London, UK: British Standard Institute.

[8] BS 5268-2. (2002). Structural use of timber-Code of practice for permissible stress design, materials and workmanship. UK, London.

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