ISSN 2229-5518

Analysis of the Cause(s) of the Collapse of a 3-Storey Building in Ile-Ife, Osun State, Nigeria

Ogunbiyi, Moses A., Olawale, S. O., Olayiwola, T. B., Bamgboye, O. A.

Abstract— This study sets out to investigate the remote cause(s) leading to the collapse of a 3-Storey Building in Ile-Ife. The study analyzed the original design submitted for approval and construction, the report of the Lagos State Materials Testing Laboratory (LSMTL) and the research re-design of the Structural elements required for the stability of the building. The results show that the building was under-designed in critical areas of the building elements such as; columns, beams, and slabs. Also, the contractor did a shoddy work either out of greed, incompetence or lack of experience. It was also, noted that inappropriate materials were used by the contractor in the construction of the building. Reinforcement provided at the first, second and third floors of the building were adequate but the design did not take into consideration hogging and cantilevers. This may result in over-turning leading to collapse of the building. The results show that the reinforcement bars provided for the beams were inadequate; it was also observed that the characteristic compressive strength; fcu(20N/mm2) recommended for reinforced concrete was not met by the constructors. The survey therefore concludes that; under-design, use of low grade concrete, poor concrete mix, poor workmanship, lack of proper supervision among other things contributed to the demise of the 3-storey building.

Index Terms— Lagos State materials Testing Laboratory (LSMTL), Structural Details, Structural Calculations, Investigation Report, Building, Structure, Pad Foundation, Average Soil Bearing Pressure (ASBP).

1 INTRODUCTION

Failure of structures generally have different severity such as; cracks, uneven-settlement, etc. the ultimate is collapse. According to [14] deterioration or decay in a structure especially in vigor or usefulness can be categorized as a failure but total loss of bearing capacity, resulting in sudden breakdown, physical depletion and/or falling apart is termed a collapse.

Among contributing factors are; structural under-design, greed, incompetence (designers and constructors), corruption, poor planning, poor workmanship, lack or improper supervision, poor or non-enforcement of prevailing codes, in adequate public awareness and education and limited financial and technical expertise among other factors.

These incidents have resulted in the question, how effective are building constructors' in Nigeria? It has also cast aspersion on the competence of the Nation's built-environment professionals; especially, architects, builders and engineers. The blame should not be laid solely at the door steps of the professionals but must be equally shared by building owners and constructors from derailing from approved plans, structural designs etc. and relying on un-scientific imagination and fantasy.

Secondly most building owners in Nigeria, shun professional advice in order to cut cost forgetting the saying "Penny Wise Pound Foolish". Thirdly, the un-regulated economy which gives rise to the high cost of building materials, leads greedy contractors to focus on profit alone and cut corners to the detriment of proper construction methodology.

This also leads to the use of sub-standard and inappropriate construction materials. This practice has contributed majorly to the failure of buildings in Nigeria. Seeley [28] suggests that all potential building sites need investigation to determine their suitability or otherwise for situating a building; nature and extent of preliminary works that may be required. He reiterates that particular attention should be paid to the type of soil and its probable load-bearing capacity, as there may be variations over the site due to non-homogeneity of soil.

Lambe and Whitman [19] define foundation as the part of the structure in direct contact with the ground and transmit the building loads to the ground and play an important role in the construction of a building. Foundation carries all the live, dead and wind loads of a structure and transmits such loads directly to the soil/ground on which the building/structure rest in such a way that there is even distribution of the loads to prevent failure.

On the other hand, [30] reiterates that poor concrete materials mixture do not make good concrete. The result of poor concrete mix is building collapse. Steel reinforcement is used in concrete to make to make up for tensile strength (lacking in concrete) for this purpose, steel reinforcement bars must be bent to regulated standards according to relevant design codes of practice. Otherwise, there will be a structural failure and subsequent collapse.

Oyewande[27] identifies deficient structural drawings as accounting for 50% of collapse of engineering structures in Nigeria. There are many other problems that have been ascribed to the causes of building collapse by many authors such as; absence of proper supervision, alteration of approved drawings, building without an approved building plans, approval of technically deficient building plans by approving authorities, illegal alteration of existing building without recourse to the as-built-drawings, greed, absence of engineering and town planning of the building during construction, lack of monitoring/proper supervision of the building during construction, clients' penchant for cutting corners and numerous other factors have been identified as causing building collapse [21].

Hall[16], Aniekwu and Orie[9] all posited that sub-standard materials, especially reinforcement rods/bars, steel sections and impure cement contribute immensely to build-

ISSN 2229-5518

ing/structural failures. It is based on this premise, that the survey sets out to investigate the remote and immediate cause(s) of the collapsed 3-Storey building in Ile-Ife.

2 Materials and Methods

Firstly, soil test was carried out at the site of the collapsed building using the penetrometer test method to determine the load-bearing capacity of the soil on which the foundation of the building rest before collapse.

Secondly the submitted structural and design details of the building given to the contractor by the design engineer was reviewed. Thirdly, findings of the investigation report (after the collapse) submitted by the Lagos State materials testing was also reviewed in relationship to the design engineer's structural requirements for the stability of the building. Finally, in order to ensure that there is no bias in the comparison of the actual structural design and the report of the investigation by the LSMTL, the researchers, re-designed the building structure based on the architectural design submitted to the planning authority for approval. This will enable the researchers to discover (if any) areas of discrepancies that may have contributed to the collapse of the 3-Storey building.

3 Results

Soil test result from the building site taken at five different locations and obtained at 1.5m depth, reveals that; the soil is fine grained, firm, moist, brown, medium-plasticity, clayey and smooth-textured. Based on this result, a pad foundation was chosen for the building.

TABLE 1

Report of Soil Test

S/No.	Sample Location	Liquid Limit	Plastic Limit	Plastic Index	Bearing Pressure
1.	Loc. 1	40	30	10	100
2.	Loc. 2	38	26	12	95
3.	Loc. 3	40	30	10	100
4.	Loc. 4	35	25	10	90
5.	Loc. 5	50	40	15	100

Therefore, average soil bearing pressure (ASBP) = 100+95+100+85+100/5 =96.0 KN/M²

From this result, pad foundation was chosen as the best fit foundation to carry the dead, live and wind loads imposed on the building.

TABLE 2

Reinforcements Requirements from the Original Design

S/No.	Building Element	Grnd. Floor	1st Floor	2nd Floor	3rd Floor
1	Column	Rectangular	Rectangular	Rectangular	Rectangular
2	Column Size(mm)	225x225	225x225	225x225	225x225
3	Req. Col. Bar Size(mm)	Y20	Y16	Y16	Y16
4	Col. Link Size(mm)	Y10	Y10	Y10	Y10
5	Link Spacing(mm)	240	240	240	240
6	No. Re-bars(mm)	4	4	4	4
7	Beam Type	-	T-Beam	T-Beam	T-Beam
8	Beam Size(mm)	-	225x450	225x450	225x450
9	Beam bar size(mm)	-	Y16	Y16	Y16
10	Link Spacing(mm)	-	200	200	200
11	Beam bar distribution	-	2	2	2
12	Slab Depth(mm)	-	150	150	150
13	Bar Distribution	-	12-2way	Y12-2way	Y12-2way
14	Bar Spacing(mm)	-	200 C/c	200 C/c	200 C/c

TABLE 3

Result of findings by the LSMTL in their report

S/No.	Building Element	Grnd. Floor	1st Floor	2nd Floor	3rd Floor
1.	Column Type	Rectangular	Rectangular	Rectangular	Rectangular
2.	Bar Size(mm)	Y16	Y16	Y16	Y16
3.	Column Size(mm)	300x300	225x225	225x225	225x225
4.	Link Size(mm)	M10	M10	M10	M10
5.	Link Spacing(mm)	240	240	240	240
6.	Bar Distribution	4	4	4	4
7.	Beam Type	-	T-Beam	T-Beam	T-Beam
8.	Beam Size(mm)	-	225x450	225x450	225x450
9.	Beam Bar Size(mm)	-	Y16	Y16	Y16
10.	Stirrup Spacing(mm)	-	200 C/c	200 C/c	200 C/c
11.	Beam Bar Distr.	-	4	4	4
12.	Slab Depth(mm)	-	150	150	150
13.	Slab Bar Size(mm)	-	Y10	Y10	Y10
14.	Slab Bar Spacing(mm)	-	200 C/c	200 C/c	200 C/c

Source: Lagos State Materials Testing Laboratory

TABLE 4

Details of Building Structural Re-design

S/No.	Building Element	Grnd. Floor	1st Floor	2nd Floor	3rd Floor
1.	Column Type	Rectangular	Rectangular	Rectangular	Rectangular
2.	Col. Size(mm)	230x300	230x300	230x300	230x300
3.	Col. Bar Size(mm)	Y20	Y20	Y20	Y20
4.	Stirrup Size(mm)	Y10	Y10	Y10	Y10
5.	Stirrup Spacing(mm)	240 C/c	240 C/c	240 C/c	240 C/c
6.	Col. Bar Distribution	6	6	4	4
7.	Beam Type	-	T-Beam	T-Beam	T-Beam
8.	Beam Size(mm)	-	230x300	230x300	230x300
9.	Beam Bar Size(mm)	-	Y16	Y16	Y16
10.	Stirrup Spacing(mm)	-	250 C/c	250 C/c	250 C/c
11.	Beam Bar Distribution	-	3	3	3
12.	Slab Depth(mm)	-	150	150	150
13.	Slab Bar Size(mm)	-	200 C/c	200 C/c	200 C/c
14.	Slab Distribution bars	-	Y12-2way	Y12-2way	Y12-2way

TABLE 5
COMPARING THE THREE STRUCTURAL CALCULATIONS

	Structural Design at Inception				Structural Findings after Collapse				Structural Re-Design			
Floors	Ground	First	Second	Third	Ground	First	Second	Third	Ground	First	Second	Third
Column Type	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular
Column Size	225×225	225×225	225×225	225×225	300×300	225×225	225×225	225×225	230×300	230×300	230×300	230×300
Column Bar size	Y20	Y16	Y16	Y16	Y16	Y16	Y16	Y16	Y20	Y20	Y20	Y20
Column Link Spacing	240	240	240	240	240	240	240	240	240	240	240	240
Column Bar Number	4	4	4	4	4	4	4	4	6	6	4	4
Beam Type	---	T-beam	T-beam	T-beam	T-beam	T-beam	T-beam	T-beam	T-beam	T-beam	T-beam	T-beam
Beam Size	---	225×450	225×450	225×450	225×450	225×450	225×450	225×450	230×300	230×300	230×300	230×300
Beam Bar Size	---	Y16	Y16	Y16	Y16	Y16	Y16	Y16	Y16	Y16	Y16	Y16
Beam Link Spacing	200	200	200	200	200	200	200	200	200	200	200	200
Beam Bar Number	2	2	2	2	2	2	2	2	3	3	3	3
Slab Depth	150	150	150	150	150	150	150	150	150	150	150	150
Slab Bar Size	---	Y12	Y12	Y12	Y10	Y10	Y10	Y10	Y12	Y12	Y12	Y12
Slab Link Spacing	200	200	200	200	200	200	200	200	200	200	200	200

4 DISCUSSION

The tables above show some discrepancies in the original design, findings of the LSMTL and the researchers' results (see appendix for detailed structural re-design of the building).

The survey deduced from the results that; low grade quality concrete employed by the contractor, poor concrete mix, poor workmanship, and poor supervision among many other factors contributed to the demise of the 3-Storey building. The study beliefs that there was an attempt on the part of the contractor to cut-corners whether with the knowledge of the owner or not; he reduced the sizes and numbers of reinforcement bars in some critical elements of the building.

Opara[34] identifies poor workmanship, use of cheap and inferior materials, wrong interpretation of building design plan, inadequate supervision, non-adherence to due process in building construction, lack of maintenance culture, greedy attitude of contractors, professional incompetence, activities of quacks, and use of plan approved for one storey building to build multi-storey building as major causes of building failure in Nigeria.

Oloyede et al[33] on the other hand attribute factors responsible for building collapse as; use of low quality building materials, employment of incompetent artisans and weak supervision of workmen on site; included are non-compliance with specifications/standards, use of substandard building materials and equipment. The study also points to non-enforcement of existing laws and endemic poor work ethics of the average Nigerian worker.

Alamu and Gana[32] attributes the rising incidents of building collapse to the use of sub-standard building materials and incompetent professionals in construction activities, inadequate supervision, faulty building foundation, refusal of the wider society to recognize professionalism and pay for the services and the attitude of contractors and other stakeholders as the major factors contributing to building collapse in Nigeria.

Results from other works corroborate the findings of the present study in identifying the underlying causes of collapse of the 3-storey building in Ile-Ife, Osun State, Nigeria. This study went further to use scientific analysis in identifying structural deficiency as a major contributor to the collapse and the scientific approach and measurement applied by the research also, contributed to knowledge of underlying cause of the building collapse. The specific research methodology of using structural engineering approach to identify the structural defect in the building design before collapse, helped in avoiding generalization of the contributing factors of the 3-storey building.

5 CONCLUSION

In conclusion, the study finds that shoddy work, lack of proper supervision, under-design of structural members and contractor's greed led to the collapse of the building in Ile-Ife, Osun State Nigeria.

ISSN 2229-5518

6 Appendix

6.1 Design Criteria

Design was in accordance with BS 8110, ultimate loads, shear force and bending moment acting on individual member was calculated, then bending ULS was checked for and this is done to determine an adequate depth for the beam and area of both compression and tension reinforcement required.

The design shear stress v at any cross-section was also calculated from: $v = \frac{V}{b_V d}$

In no case should shear stress v exceed $0.8\sqrt{f_{cu}}$ or 5 N/mm^2, whichever is the lesser, whatever shear reinforcement is provided.

Spacing of links

The spacing of links in the direction of the span was designed not to exceed 0.75d. At right-angles to the span, the horizontal spacing was such that no longitudinal tension bar is more than 150 mm; this spacing should in any case not exceed d. Minimum links provide a design shear resistance of $0.4N/mm^2$.

Solid slabs

In general the recommendations given for beams were applied and also to solid slabs.

Simply-supported slabs

When simply-supported slabs do not have adequate provision to resist torsion at the corners, and to prevent the corners from lifting, the maximum moments per unit width are given by the following equations:

msx = $\propto$ sxnlx2

msy = $\propto$ synlx2

Shear stresses

The design shear stress 'v' at any cross-section should be calculated from equation 21:

$$v = \frac{V}{bd}$$

In no case should 'v' exceed $0.8\sqrt{fcu}$ or 5 N/mm2, whichever is the lesser, and whatever shear reinforcement is provided.

Deflection

Deflections was calculated and compared with the serviceability requirements given but in all normal cases, it will be sufficient to restrict the span/effective depth ratio. The ratio for a two-way (2-way) spanning slab should be based on the shorter span.

Columns: Analysis of sections

In the analysis of a column cross-section to determine its design ultimate resistance to moment and axial force, the same assumptions was made as when analyzing a beam.

Short and slender columns

A column may be considered as short when both the ratios l_{ex}/h and l_{ey}/b are less than 15 (braced) and 10 (un-braced). It should otherwise be considered as slender.

Nominal eccentricity of short columns resisting moments and axial forces

Short columns usually need only to be designed for the maximum design moment about the one critical axis. Due to the nature of a structure, a column cannot be subjected to significant moment it may be designed so that the design ultimate axial load does not exceed the value of N given by:

$N = 0.4f_{cu}A_c + 0.8A_{sc}f_y$

Short braced columns supporting an approximately symmetrical arrangement of beams

The design ultimate axial load for a short column of this type may be calculated using the equation below:

$N = 0.35f_{cu}A_c + 0.7A_{sc}f_y$

Foundation

Various soil tests such as Penetrometer, Atterberg limits, Compressive Strength tests were carried out to obtain the Soil bearing capacity which was used to re-design the foundation footing.

Design moment on a vertical section taken completely across a pad footing

The design moment on a vertical section taken completely across a pad footing was taken as that due to all external design ultimate loads and reactions on one side of that section. No redistribution of moments was be made.

Design shear

The design shear is the algebraic sum of all design ultimate vertical loads acting on one side of or outside the periphery of the critical section. The shear stress at the column face should not be less than the lower of 5N/mm2 or $0.8\sqrt{fcu}$. Then, punching shear stress was checked for which is 1.5d away from the face of the column. Reinforcement to resist bending at the column face which is the critical section is then calculated using the equation below:

$As = M / 0.87fy_z$

The overall stability at the ultimate limit state was checked.

TABLE 6: REPORT OF THE LSMTL

Ground Floor

Structural Element	Average Compressive Strength (N/mm^2)	Remark
COLUMN 1	11.9	POOR
COLUMN 2	12.1	POOR
COLUMN 3	10.7	POOR
COLUMN 4	10.3	POOR
COLUMN 5	8.8	POOR
COLUMN 6	14.0	POOR
COLUMN 7	10.1	POOR

ISSN 2229-5518

COLUMN 8	12.0	POOR
COLUMN 9	12.8	POOR
COLUMN 10	15.1	POOR
COLUMN 11	13.1	POOR
COLUMN 12	14.4	POOR
COLUMN 13	11.0	POOR
COLUMN 14	15.3	POOR
COLUMN 15	15.3	POOR
COLUMN 16	12.8	POOR
COLUMN 17	14.3	POOR
COLUMN 18	11.7	POOR
COLUMN 19	11.0	POOR

TABLE 7

FIRST FLOOR

Structural Element	Average Compressive Strength(N/mm^2)	Remark
COLUMN 1	13.3	POOR
COLUMN 2	14.0	POOR
COLUMN 3	17.0	GOOD
COLUMN 4	18.0	GOOD
COLUMN 5	15.0	POOR
COLUMN 6	12.2	POOR
COLUMN 7	12.0	POOR
COLUMN 8	9.7	POOR
COLUMN 9	8.5	POOR
COLUMN 10	13.0	POOR
COLUMN 11	10.2	POOR
COLUMN 12	12.1	POOR
COLUMN 13	11.2	POOR
COLUMN 14	11.7	POOR
COLUMN 15	11.5	POOR
COLUMN 16	9.9	POOR
COLUMN 17	9.4	POOR
COLUMN 18	14.1	POOR
COLUMN 19	11.6	POOR
COLUMN 20	11.4	POOR
BEAM 1	14.3	POOR
BEAM 2	9.0	POOR
BEAM 3	10.0	POOR
BEAM 4	12.0	POOR
SLAB 1	17.0	GOOD
SLAB 2	13.9	POOR
SLAB 3	15.0	POOR
SLAB 4	15.1	POOR

TABLE 8

SECOND FLOOR

Structural Element	Average Compressive Strength(N/mm^2)	Remark
COLUMN 1	18.7	GOOD
COLUMN 2	17.1	GOOD
COLUMN 3	16.4	GOOD
COLUMN 4	115.3	GOOD
COLUMN 5	15.7	POOR
COLUMN 6	15.7	POOR
COLUMN 7	12.1	POOR
COLUMN 8	12.6	POOR
COLUMN 9	13.5	POOR
COLUMN 10	11.4	POOR
COLUMN 11	11.9	POOR
COLUMN 12	10.5	POOR
COLUMN 13	10.8	POOR
COLUMN 14	11.4	POOR
COLUMN 15	12.4	POOR
COLUMN 16	10.0	POOR
COLUMN 17	11.3	POOR
COLUMN 18	12.4	POOR
COLUMN 19	10.6	POOR
COLUMN 20	9.7	POOR
BEAM 1	10.3	POOR
BEAM 2	13.4	POOR
BEAM 3	18.0	GOOD
BEAM 4	17.0	GOOD
SLAB 1	21.7	GOOD
SLAB 2	17.7	GOOD
SLAB 3	17.0	GOOD
SLAB 4	14.3	POOR

TABLE 9

THIRD FLOOR

Structural Element	Average Compressive Strength(N/mm^2)	Remark
COLUMN 1	13.6	POOR
COLUMN 2	13.9	POOR
COLUMN 3	12.6	POOR
COLUMN 4	18.7	GOOD
COLUMN 5	15.8	POOR
COLUMN 6	12.5	POOR
COLUMN 7	16.1	POOR
COLUMN 8	17.0	GOOD
COLUMN 9	18.3	GOOD
COLUMN 10	10.7	POOR
COLUMN 11	11.8	POOR
COLUMN 12	12.0	POOR
COLUMN 13	20.6	GOOD
COLUMN 14	19.0	GOOD
BEAM 1	9.9	POOR
BEAM 2	10.3	POOR
BEAM 3	10.8	POOR
BEAM 4	13.2	POOR
SLAB 1	9.8	POOR
SLAB 2	16.3	POOR
SLAB 3	13.5	POOR
SLAB 4	16.3	POOR

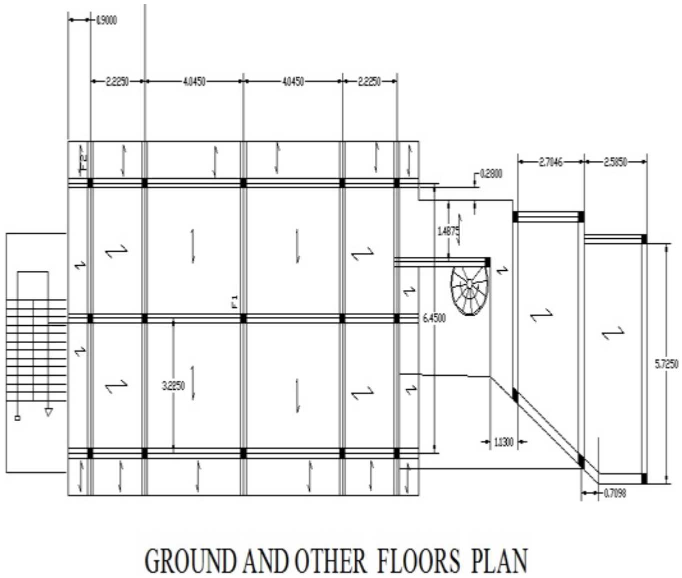


Fig. 1. Ground and other floors plan

SLAB DESIGN

Materials used = Grade 20 concrete and high yield 410mm bars

Depth of slab: 150mm

Study adopts the effective depth (d) = 119mm

Loads

Self-weight of slab = (24 x 0.15) = 3.6 kN/m²

Finishes= 1.5 kN/m²

Partition= 1.0kN/m²

Total working load = w = 6.1 kN/m²

Imposed load = 2 kN/m²

Therefore maximum design ultimate load = (1.4Gk+1.6Qk)

= (1.4 x 6.1 +1.6 x 2) x 1m

=11.74 kN/m

Minimum design ultimate load = (1.4 x 6.1) x1m= 8.54 kN/m

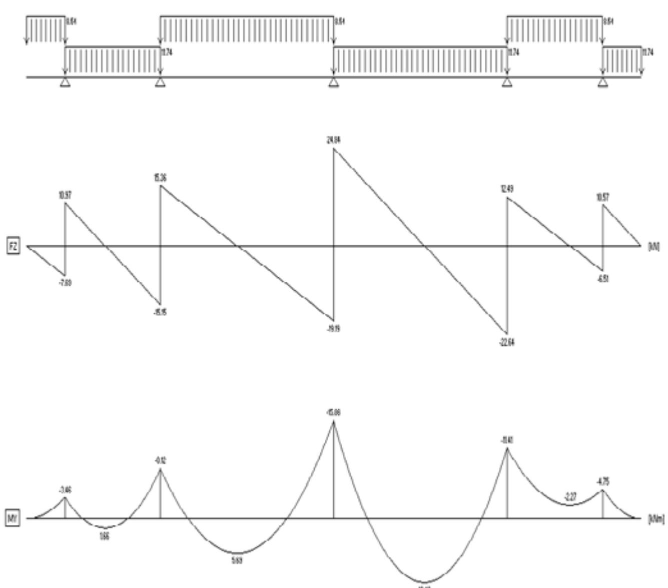


Fig. 2. Moment calculation

Steel reinforcement

Moment = 15.86KNm

K = M/bd2fcu = 15.86 x 106 / 1000 x 1192 x 20= 0.06

Z = d [0.5 + $\sqrt{(0.25-k/0.9}$]=119[0.5+ $\sqrt{0.25-0.06/0.9}$]

Z = 110.45mm

As required= $\dfrac{M}{0.87\,fyz}$ = 15.86 x 10⁶ / 0.87 x 410 x 110.45 = 402.56mm² > As_{min}

Minimum requirement= $\dfrac{0.1366}{100}$ $=\dfrac{0.13x1000x150}{100}$ =

195mm2 OK

Provide 12mm bar @200 center to center (As = 566mm²)

Deflection check

Actual span / effective depth =26

4045 / 119 = 33.99

$$F_s = \frac{5}{8}\,fy\,\frac{Asreq}{Asprov} = \frac{5}{8}x410x\frac{402.56}{566} = 182.25\text{N/mm}^2$$

Modification factor = 0.55 + 477 – f_s / 120 (0.9 + m/bd²)

M/bd² = 15.86 x 10⁶ / 1000 x 119² = 1.12

M_f = 1.77

From table 3.14 of BS 8110, basic span to effective depth ratio is 26

Permissible span / effective depth = basic ratio x M_f = 26x1.77 = 46.02 > 33.99 OK

End support

Moment = 4.75KNm

K = M/bd²fcu = 4.75 x 10⁶ / 1000 x 119² x 20 = 0.02

Z = $d[0.5+\sqrt{0.25-\dfrac{k}{0.9}}]$

Z = $d[0.5+\sqrt{0.25-\dfrac{0.02}{0.9}}]$

Z = 0.977d, use 0.95d = 113.05

As req. = $\dfrac{M}{087\,fyz}$ = 4.75 x10⁶ /0.87 x 410 x 113.05 = 179.80mm²

Provide 12mm @ 300 center to center (A_s = 377mm²)

Deflection check

Actual span / effective depth = 900/119 = 7.56

$$F_s = \frac{5}{8}\,fy\,\frac{asreq}{asprov} == \frac{5}{8}x410x\frac{179.80}{377} = 122.21N/mm2$$

Mf = 0.55 + 477 – fs / 120(0.9 + m / bd²)

M / bd² = 4.75 x 10⁶ / 1000 x 119² = 0.34

ISSN 2229-5518

$$M_f = 0.55 + \frac{477 - 122.21}{120(0.9 + 0.34)}$$

$M_f = 3.23$

Permissible span / effective depth = 7 x 3.23 = 22.61 > 7.56 OK

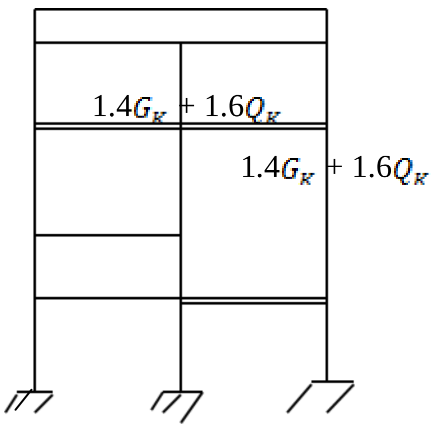


Fig. 3. Column Design

Critical load arrangement for centre columns
Column size=230x300mm

Maximum Ultimate Load at each floor=3.225(1.4GK+1.6Qk)
=3.225(1.4x26.9135+1.6x6.6)
=155.57kN/m

Minimum Ultimate load at each floor = 3.225(1.4Gk)
=3.225x1.4x26.9135
=121.51kN/m

Column Loads

2nd and 3rd floors =2x155.57x3.225=1003.4256kN

First Floor=155.57x$3.225/2$+121.51x$3.225/2$ =446.7915kN

Column Self weight =2x14=28kN
1478.218kN

Column Moments

Member stiffness's are:

$KAB/2$=$1/2\ \ bh^3/12LAB$=$1/2$x

$0.23x0.3^3/12x3.225$=0.8x10^{-4}

$KBC/2$=$KAB/2$

K_{BE}=K_{BH}=K_{COL}=$bh^3/12LAB$x

0.5=$0.23x0.3^3/12x3.3$=1.568x10^{-4}

Total Stiffness= (1.568+1.568+0.8+0.8)10^{-4}
= 4.736 x 10^{-4}

Distribution factor at joint B

D_FBE=

$(1.568x\ \ 【10】\ \ ^{\wedge}(-4))/(4.736x\ \ 【10】\ \ ^{\wedge}(-4)\ )$=0.33

D_F BE=D_F BH

$D_F\ \ BA$=$D_F\ \ BC$=$0.8/4.736$=0.169

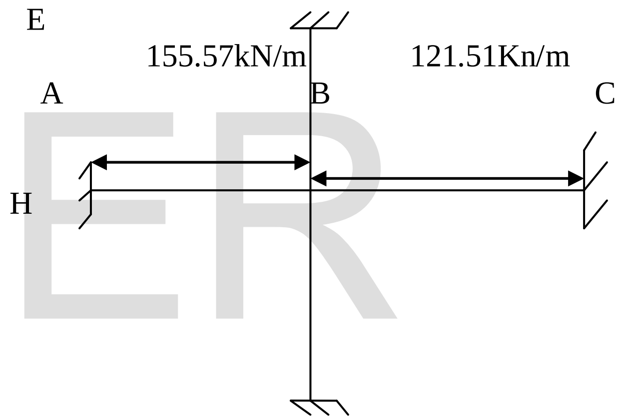


Fig. 4. The moment distribution

TABLE 10
THE MOMENT DISTRIBUTION

Joint	E	A					C	H
	EB	AB	BA	BE	BH	BC	CB	HB
D.F	0	0	0.17	0.33	0.33	0.17	0	0
F_{EM}	-	+134.84	+134.84			-105.31	+105.31	
BAL.			-5.02	-9.74	-9.74	-5.02		
CO.	-4.87	-2.51					-2.51	-4.87
	-4.87	-137.35	129.82	-9.74	-9.74	-110.33	102.8	-4.87

International Journal of Scientific & Engineering Research, Volume 6, Issue 12, December-2015
ISSN 2229-5518

Design moment in the lower column at section X-X;
Design Axial load, N=1478.218kN
Moment = 9.74kNm
Column is braced.
Assume the effective height of column section at BH=3.3m about both axes.

X-X direction $lex/h = \frac{3300}{230} = 14.35$

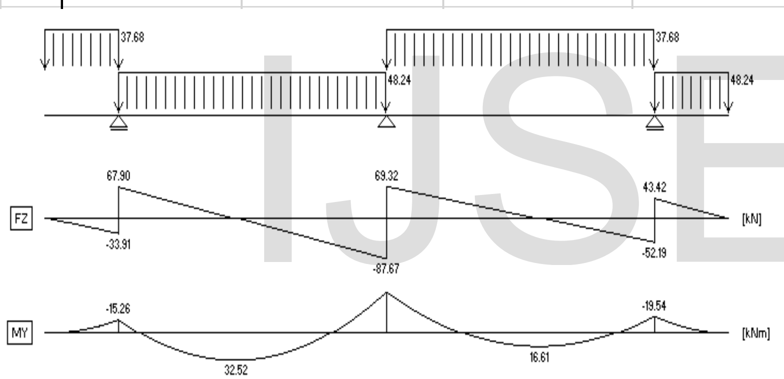
Y-Y direction $ley/h = \frac{3300}{300} = 11$

Column is short.
Assume a bar diameter=20mm
Cover=25mm, link=8mm
Effective depth, d= (300-25-8-10)
=257mm

$d/h = 257/300 = 0.86$
Using design chart, Fig 3.94 from BS8110
$N/bh = (1478.218x\ [10]^3)/230x300 = 21.42$
$M/bh^2 = (9.74x\ [10]^6)/(230x\ [300]^2) = 0.47$
From design chart;
$100Asc/bh = 2.2$; $Asc = 2.2x230x300/100 = 1518mm^2$

Provide 6Y20 (Asc=1890mm²)
Minimum link diameter ≥0.25x largest compression bar
=0.25x20=5
8mm≥5mm
Spacing of links ≤ (12x smallest compression bar)
=12x20=240mm
Provide 10mm diameter links at 240mm Spacing.

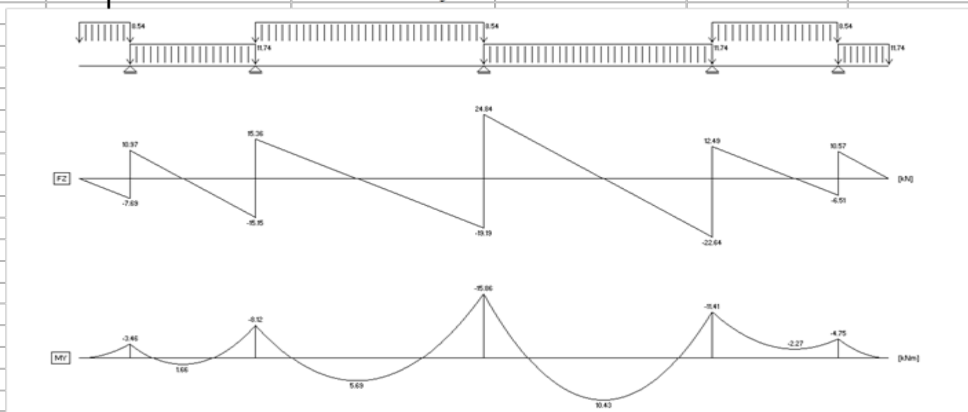
REFERENCE				CALCULATIONS				OUTPUT	943
				BEAM	(230 x	300) mm			1260
									1570
									1890
							d =	255 mm	2200
		S/w of Beam	(24×0.230×0.45) +(	=	18.93 kN/m		Span=	3225 mm	2510
				say	20.00 kN/m		Zero Mnt	2258 mm	
		Wall load	2.42×3.3 =	7.99 kN/m			bf (Tee) =	682 mm	
			say	8.00 kN/m			bf (ELL) =	456 mm	
									Pı



									1
									2
									3
									4
									5
									6
									7
									8
		Span Reinf.	32.52 kNm	Designed as a	T- Section bf =	513 mm			
		M_{span} =	32.52 kNm	< Span M_{ult} =	46.66 kN/m				
	k =	0.05 <	0.156				fcu =	20 N/sq.mm	
	la =	0.94 >	0.95 else adopt	0.94			fy =	410 N/sq.mm	
	As=	347.4 sq.mm							
			Hence, Provide	2 Y16mm Btm	(402 sq.mm)				
			Alternatively,	2 Y20mm Btm	(628 sq.mm)			2 Y16mm Btm	
		Spt Reinf.	47.15 kNm	Designed as a	Rectangular Section				
		$M_{support}$ =	47.15 kNm	< Spt.M_{ult} =	46.66 kN/m				
	k =	0.16 <	0.156						
	la =	0.77 <	0.95 else adopt	0.77					
	As=	613.7 sq.mm							
			Hence, Provide	4 Y16mm top	(804 sq.mm)			3Y20mm top	
			Alternatively,	3Y20mm top	(943 sq.mm)				
		Deflection Check.							
		As Prov. =	402 sq.mm		M/bd^2 =	0.97			
		F.s =	2 x 347.4 x	410	Max. M.F	2.00			
			3 x 402.0	= 236.19	Used M.F	1.62			
		M.F =	477 - 236.2	+ 0.55					
			120(0.9+0.97)	=	1.62				
		Depth Reqd (mm) =		86.5 mm <	255mm	SATISFACTORY!			
		Shear Reinforcement.							
		Shear Force. V. (KN) =		211.3KN					
		v.(N/sqmm). = V/bd =		3.60N/sq.mm					
			v_c =	0.62N/sq.mm		And, S_V =	89 mm		
			Provide Y	10 @	250 centres				
			2	(Legs)	LINKS				

ISSN 2229-5518

REFERENCE				CALCULATIONS				OUTPUT	943
									1260
				BEAM	(230 x	300) mm			1570
									1890
							d =	255 mm	2200
		S/w of Beam	(24×0.230×0.45) +(	=	18.93 kN/m		Span=	4045 mm	2510
				say	20.00 kN/m		Zero Mnt	2832 mm	
		Wall load	2.42×3.3 =	7.99 kN/m			bf (Tee) =	796 mm	
			say	8.00 kN/m			bf (ELL) =	513 mm	



		Span Reinf	20.55 kNm	Designed as a	T- Section bf=	513 mm			
		M_{span} =	20.55 kNm	< Span M_{ult} =	46.66 kN/m				
	k =	0.03 <	0.156				fcu =	20 N/sq.mm	
	la =	0.96 >	0.95 else adopt	0.95			fy =	410 N/sq.mm	
	As=	217.8 sq.mm							
			Hence, Provide	2 Y16mm Btm	(402 sq.mm)				
			Alternatively,	#N/A	#N/A			2 Y16mm Btm	
		Spt Reinf	15.86 kNm	Designed as a	Rectangular Section				
		$M_{support}$ =	15.86 kNm	< Spt.M_{ult} =	46.66 kN/m				
	k =	0.05 <	0.156						
	la =	0.94 <	0.95 else adopt	0.94					
	As=	170.4 sq.mm							
			Hence, Provide	#N/A	#N/A			3Y20mm top	
			Alternatively,	3Y20mm top	(943 sq.mm)				
		Deflection Check.							
		As Prov. =	402 sq.mm		M/bd^2 =	0.62			
		F.s =	2 x 217.8 x	410	Max. M.F	2.00			
			3 x 402.0	= 148.08	Used M.F	2.00			
		M.F =	477 - 148.1	+ 0.55					
			120(0.9+0.62)	=	2.36				
		Depth Reqd (mm) =		87.9 mm <	255mm	SATISFACTORY!			
		Shear Reinforcement.							
		Shear Force. V. (KN) =		211.3KN					
		v.(N/sqmm). = V/bd =		3.60N/sq.mm					
			v_c =	0.62N/sq.mm		And, Sv=	89 mm		
		Provide Y		10 @	250 centres				
			2	(Legs)	LINKS				

Foundation Footing Design

Footing (f1) Loading

Dead load= 86.80kN/m

Live load= 21.29kN/m

Serviceability load

Maximum load= 1.0Gk + 1.0Qk

=1.0 x 86.8 +1.0 x 21.29

=108.08kN/m

Minimum load= 1.0Qk

=1.0x86.8

=86.80kN/m

Total column load

2nd and 3rd floors= 2x108.08x3.225= 697.12kN

1^{st} floor= $108.08 \times \frac{3.225}{2} + 86.80 \times \frac{3.225}{2} = 314.244$

Total load = 1011.36kN

Bearing pressure = 100kN/m^2

Area of footing = $\frac{1011.36}{100} = 10.1136 m^2$

Provide a 3.2m square base (plan area=10.24 m^2)

Assume the overall depth of footing = 600mm

ISSN 2229-5518

Bending Reinforcement

Total ultimate load (W) = 1478.218kN

Earth pressure (ps) = $\dfrac{1478.218}{10.24}$ =144.36kN/m^2

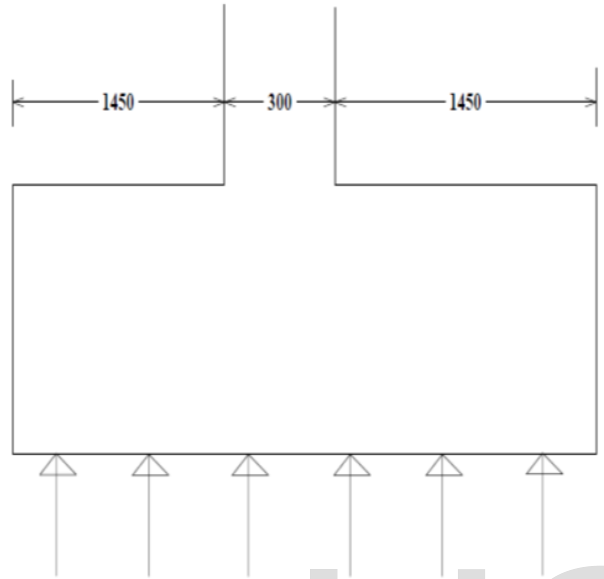


Fig. 5. Pressure distribution for footing (F1)

Maximum design moment occur at the face of the column= 144.36 x3.2 x 1.6^2 /2 = 591.30kNm
Assume cover= 50mm, Bar diameter = 25mm
Effective depth = 600-50-25=525mm

Ultimate moment, Mu= 0.156 x25 x1000 x525^2
=860kNm
Since Mu > M, no compression reinforcement is required.
Design moment = 591.30KNm
K = M/bd^{2}fcu = 591.30 x 10^6 / 1000 x 525^2 x 20 = 0.11

$$Z = d[0.5+\sqrt{0.25-\frac{k}{0.9}}]$$

$$Z = d[0.5+\sqrt{0.25-\frac{0.11}{0.9}}] = 0.86d$$

Z= 0.86 x 525 = 451.5mm

As req = $\dfrac{M}{087\, fyz}$ = 591.30 x10^6 /0.87 x 410 x 451.5 = 3671.5mm^2

Provide 25mm @ 125mm center to center (A_s = 3930mm^2)
As minimum = 0.13%bh = 780 mm^2 < As OK

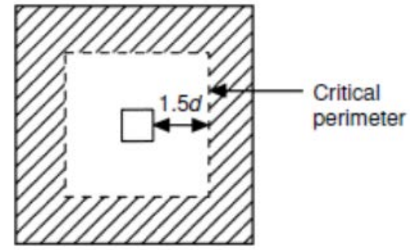


Fig. 6. Punching Shear

The critical section for checking punching is at a distance 1.5d
Critical perimeter = column perimeter + 8 x 1.5d = 4 x 300 + 8 x 1.5 x 525= 7500mm

Area within perimeter is;
(300 + 3d)^2 = (300 + 3 x 525)2 = 3.52 x 10^6 mm^2
Ultimate punching force, V, is
V = load on shaded area =144.36 x (10.24 - 3.52) = 970.10 kN
Design punching shear stress, v, is

v= $\dfrac{V}{Pcrit \times d}$ = 970.10 x10^3 / 7500 x525 = 0.25 N/mm^2

$\dfrac{100As}{bd} = \dfrac{100 \times 3930}{1000x525}$ = 0.75N/mm^2

Design concrete shear stress, vc, is;
vc = (fcu/25)$^{1/3}$ = (20/25)$^{1/3}$ x 0.57 = 0.53N/mm^2
Since vc >v, punching failure is unlikely and a 600 mm depth is acceptable.

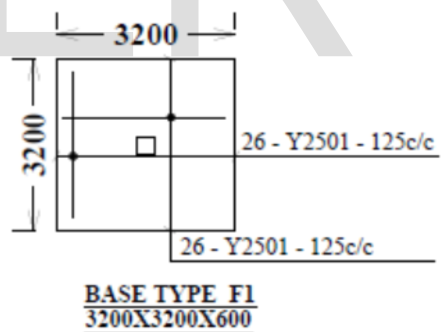


Fig. 7. Column Base Design

Footing (f2) Loading
Dead load= 59.88kN/m
Live load= 14.69kN/m
Serviceability load
Maximum load= 1.0Gk + 1.0Qk =1.0 x 59.88 +1.0 x 14.69 =74.57kN/m
Minimum load= 1.0Qk =1.0x59.88 =59.88.kN/m

Total column load
2nd and 3rd floors= 2x74.57x2.225= 331.84kN

1st floor= 74.57x$\dfrac{2.225}{2}$ + 59.88x$\dfrac{2.225}{2}$ =149.58kN

ISSN 2229-5518

Total load = 481.42kN

Bearing pressure = 100kN/m^2

Area of footing = $\frac{481.42}{100}$ = 4.816m^2

Provide a 2.2m square base (plan area=4.84 m^2)

Assume the overall depth of footing = 400mm

BENDING REINFORCEMENT

Total ultimate load (W) = 718.31kN

Earth pressure (ps) = $\frac{718.31}{4.84}$ =148.41kN/m^2

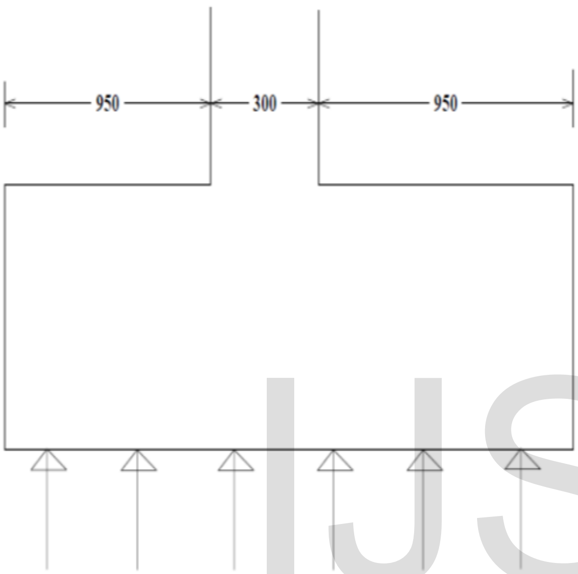


Fig. 8. Pressure distribution for footing (F2)

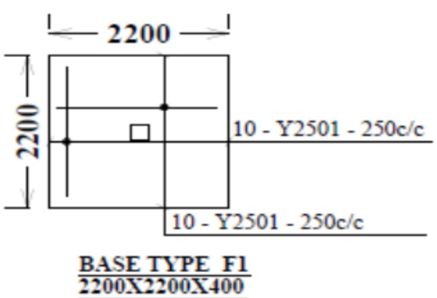


Fig. 9. Column Base Design

Maximum design moment occur at the face of the column= 148.41 x2.2 x 1.1^2 /2= 197.53kNm

Assume cover= 50mm, Bar diameter = 25mm

Effective depth = 400-50-25=325mm

Ultimate moment, Mu= 0.156 x25 x1000 x325^2

=411.94kNm

Since Mu > M, no compression reinforcement is required.

Moment = 197.53KNm

K = M/bd^2fcu = 197.53 x 10^6 / 1000 x 325^2 x 20 = 0.094

Z = $d[0.5+\sqrt{0.25-\frac{k}{0.9}}]$

Z = $d[0.5+\sqrt{0.25-\frac{0.11}{0.9}}]$ =0.88d

Z= 0.88 x 325 = 286.50mm

As req = $\frac{M}{087\,fyz}$ =197.53x10^6 /0.87 x 410 x 286.50 = 1932.88mm^2

Provide 25mm @ 250mm center to center (A_s = 1960mm^2)

As minimum = 0.13%bh = 520 mm^2 < As OK

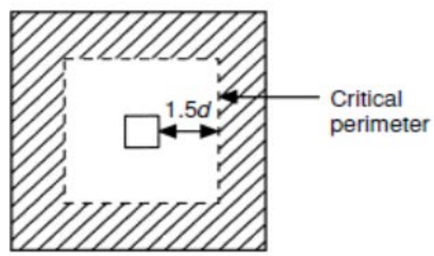


Fig. 10. Punching Shear

The critical section for checking punching is at a distance 1.5d

Critical perimeter = column perimeter + 8 x 1.5d = 4 x 300 + 8 x 1.5 x 325= 5100mm

Area within perimeter is;

$(300 + 3d)^2 = (300 + 3 \times 325)^2 = 1.63 \times 10^6$ mm^2

Ultimate punching force, V, is

V = load on shaded area =148.41 x (4.84 – 1.63) = 476.40 kN

Design punching shear stress, v, is

v= $\frac{V}{Pcrit \times d}$ =476.40x10^3/5100x325 = 0.29 N/mm^2

$\frac{100As}{bd} = \frac{100 \times 1960}{1000\text{x}325}$ = 0.60N/mm^2

Design concrete shear stress, vc, is

vc = $(fcu/25)^{1/3}$ = $(20/25)^{1/3}$ x 0.54 = 0.50N/mm^2.

Since vc >v, punching failure is unlikely and a 600 mm depth of slab is acceptable.

ISSN 2229-5518

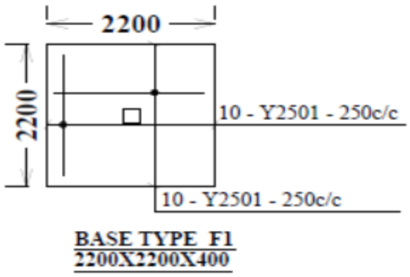


Fig. 11. Column Base design

TABLE 11

VALUES OF DESIGN CONCRETE SHEAR STRESS, VC (N/MM^2)

$\frac{100A_s}{bd}$	Effective depth (d) mm							
	125	150	175	200	225	250	300	≥ 400
≤ 0.15	0.45	0.43	0.41	0.40	0.39	0.38	0.36	0.34
0.25	0.53	0.51	0.49	0.47	0.46	0.45	0.43	0.40
0.50	0.57	0.64	0.62	0.60	0.58	0.56	0.54	0.50
0.75	0.77	0.73	0.71	0.68	0.66	0.65	0.62	0.57
1.00	0.84	0.81	0.78	0.75	0.73	0.71	0.68	0.63
1.50	0.97	0.92	0.89	0.86	0.83	0.81	0.78	0.72
2.00	1.06	1.02	0.98	0.95	0.92	0.89	0.86	0.80
≥ 3.00	1.22	1.16	1.12	1.08	1.05	1.02	0.98	0.91

TABLE 12

CROSS-SECTIONAL AREAS OF GROUP OF BARS (MM^2)

Bar size (mm)	Number of bars									
	1	2	3	4	5	6	7	8	9	10
6	28.3	56.6	84.9	113	142	170	198	226	255	283
8	50.3	101	151	201	252	302	352	402	453	503
10	78.5	157	236	314	393	471	550	628	707	785
12	113	226	339	452	566	679	792	905	1020	1130
16	201	402	603	804	1010	1210	1410	1610	1810	2010
20	314	628	943	1260	1570	1890	2200	2510	2830	3140
25	491	982	1470	1960	2450	2950	3440	3930	4420	4910
32	804	1610	2410	3220	4020	4830	5630	6430	7240	8040
40	1260	2510	3770	5030	6280	7540	8800	10100	11300	12600

TABLE 13

VALUES OF A_{SV}/S_V

Diameter (mm)	Spacing of links (mm)										
	85	90	100	125	150	175	200	225	250	275	300
8	1.183	1.118	1.006	0.805	0.671	0.575	0.503	0.447	0.402	0.366	0.335
10	1.847	1.744	1.57	1.256	1.047	0.897	0.785	0.698	0.628	0.571	0.523
12	2.659	2.511	2.26	1.808	1.507	1.291	1.13	1.004	0.904	0.822	0.753
16	4.729	4.467	4.02	3.216	2.68	2.297	2.01	1.787	1.608	1.462	1.34

TABLE 14

CROSS-SECTIONAL AREA PER METRE WIDTH FOR VARIOUS BAR SPACING (MM^2)

Bar size (mm)	Spacing of bars								
	50	75	100	125	150	175	200	250	300
6	566	377	283	226	189	162	142	113	94.3
8	1010	671	503	402	335	287	252	201	168
10	1570	1050	785	628	523	449	393	314	262
12	2260	1510	1130	905	754	646	566	452	377
16	4020	2680	2010	1610	1340	1150	1010	804	670
20	6280	4190	3140	2510	2090	1800	1570	1260	1050
25	9820	6550	4910	3930	3270	2810	2450	1960	1640
32	16100	10700	8040	6430	5360	4600	4020	3220	2680
40	25100	16800	12600	10100	8380	7180	6280	5030	4190

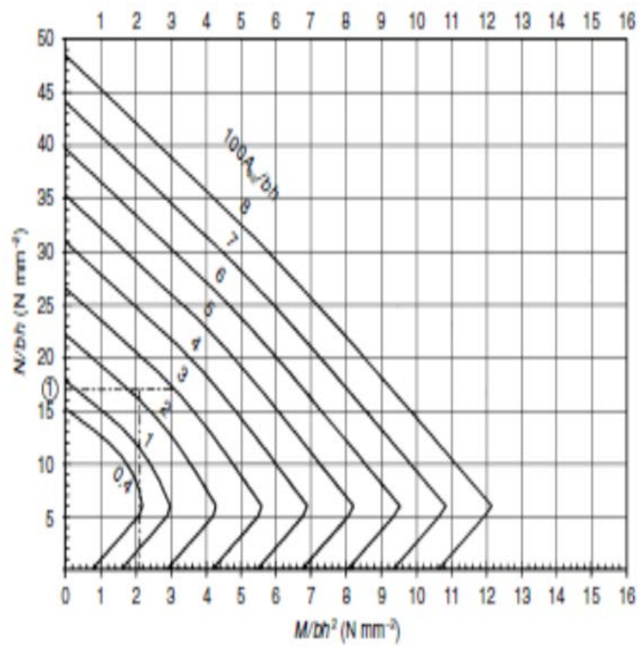


Fig. 12. Column design chart

REFERENCES

[1] T. Draycott and P. Bullmen, "Structural Elements Design Manual,"Working with Euro-codes Second Edition, Elsevier Ltd, Oxford, 2009.

[2] S.O. Adebayo ,"Improving Building Techniques," *Proceedings of a Workshop on Building Collapse: Causes, Prevention and Remedies*, The Nigerian Institute of Building, Lagos State Chapter, pp.30-35,January, 2000.

[3] A. Al – Barrak, "Causes of contractors failures," Department of Construction Engineering and Management, King Fahd University of Petroleum and Minerals, Saudi Arabia, 1993.

[4] A. Adeniya, " How Public-Private Partnership can Tackle Building Collapse," The Guardian, pp.45, Monday, August 26, 2002.

[5] O.A. Adenuga, "Building Maintenance in Nigeria: Structural Deterioration, Ignition and Diagnosis of causes and Remedies," Shelter watch, Vol. 1 pp. 5-25, June-July, 1999.

[6] T.A. Akeju, "Lessons from recent structural failures," The Nigerian Engineer, Vol.19, No.2, pp. 20-27, 1984.

[7] C. Alan, " Building Failures Recovering the Cost," 1st Edition, London, BSP Professional Books, 1990.

[8] C.O. Amobi, "Pro-active measures to avoid failures and collapse of buildings in Nigeria," *Journal of the Nigerian Institute of Building*, Vol. 13, No 2, pp. 25–29, 2006.

[9] N. Aniekwu and O.U. Orie, "The Determination of Severity Indices of variables that Cause Collapse of Engineering Facilities in Nigeria: A Case Study of Benin City," *Journal of Engineering Science and Application (JESA)* Vol.4, No. 2, pp. 63 -70, 2005.

[10] G.M. Ayininuola and O.O. Olalusi, "Assessment of building failures in Nigeria: Lagos and Ibadan Case Study" *African Journal of Science and Technology (AJST) Science and Engineering Series* Vol.5, No 1, pp. 73–78, 2004.

[11] BS 8110, Structural use of Concrete , Part 1 Code of practice for design and Construction, 1997.

[12] B.T. Hunt, Tony Hunt's Structures Notebook: Second Edition, Architectural Press, Oxford, 2003.

[13] F. Bell, "Engineering Properties of Soil and Rocks," Butterworth-Heinemann, 3rd Edition, pp. 1-2, 1987.

[14] F. Falobi, "Nigeria Tackling Disaster at Grassroots in Lagos," Daily Independent Newspaper, http://www.dailysunnewspapers.ng. July, 20,2009.

[15] O.E. Freddy, " Maintenance and Rehabilitation of Capital Assets," *Journal of Nigerian Institute of Quantity Surveyors*, Vol.27, No 2, pp. 27–28, 1999.

[16] G.T. Hall, Revision Notes on Building Maintenance and Adaptation, Butterworts and Co., England, 1984.

[17] R.O. Ilesanmi, "Maintenance Problems in Building and their Solutions," *Journal of Structural Engineers*, Vol. 1, pp. 68–72, 1988.

[18] D. James and W.H. Ransom, "Understanding Building failures" 3rd Edition, pp.8, 2007.

[19] T.W. Lambe and R.V.Whitman, "Soil Mechanics," John Wiley & Sons, 3rd Edition, pp.3-4, 1979.

[20] MacGinley, "Steel Structures Practical Design Studies" Second edition, 1998.

[21] L.E.C. Madu, "Averting the Increasing Incidents of Collapsed Buildings," The Vanguard, pp. 36, November 29, 2005.

[22] D.F.McCarthy, "Essentials of Soil Mechanics and Foundations," Cited in Criterion McCarthy Engineers, 1999.

[23] A.H. Mohammed, "Building Failures: Parts 1 &2," 2009.

[24] A. M. Neville and M. Chattertton, "New Concrete Technology and Building Design," Longman Singapore Publishers Ltd., pp. 69, 1978.

[25] A.M. Olajumoke, I.A. Oke, A.B. Fajobi and M.O. Ogedengbe, Technical Assessment and Remediation of a Failed Building in Osun State of Nigeria, *Journal of Applied Sciences Research*, Vol.2, No 8, pp. 462–465, 2006.

[26] B.O. Olateju, "Effective Contract Management in the Construction Industry," Paper presented at a Conference in Lagos, 1991.

[27] B. Oyewande, "A Research for Quality in the Construction Industry," Builders' Magazine, Lagos, June/July, 1992.

[28] I. H. Seeley, " Building Technology," Macmillan Press, 3rd Edition, pp. 2, 3, 7-11, 1987.

[29] G. Subair, "Building Nigerian," Tribune: Business and Economy; Jan 2008.

[30] M. J. Tomilson, " Foundation Design and Construction," Pitman Advanced Publishing, 4th Edition, pp. 758, 1980.

[31] O.A.Uzokwe, "Rising Incidence of Building Collapse in Nigeria: Any Remedy?" 2001.

[32] F.B. Alamu and M.S. Gana, "An Investigation on the Causes of Building Collapse in Nigeria," *Journal of Environmental Sciences and Resources Management*, Vol.6, No.1, pp.12-22, 2014.

[33] S.A. Oloyede, C.B. Omogun and O.A. Akinjare, "Tracking causes of Building collapse in Nigeria," *Journal of Sustainable Development*, Vol.3, No.3, pp.127-132, 2010.

[34] P.N. Opara, "Building Failures and Collapse: A case study of Port-Harcourt, Nigeria," *Journal of Technology and Education in Nigeria*, Vol.12(1), pp.35-39, 2007.