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Structural Analysis for Rehabilitation of Reinforced Concrete Structure

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ABSTRACT

The structural element – basement raft of the Beach resort started showing symptoms of distressed within10 years on its completion. This deterioration has aggravated further during next 3-4 years and the basement floor became obsolete functionally. Therefore, it was decided to identify the cause of failure of the structural element in terms of inadequacy of the structural element. The failure may be due to inadequacies in the design and detailing or defects during construction. This study dealt with the analysis of existing structural member for its design adequacy and to ascertain defects during construction. Design adequacy was ascertained using computer aided software- (STADD -Pro). Defects during construction have been ascertained by establishing the Sectional details of the As built basement raft in terms of dimensional parameters, noted on site as well as quality parameters confirmed in laboratory testing. On analysing these cases, the actual cause of the structural failure of the basement raft has been concluded.

Keywords: Rehabilitation, Structure, laboratory tests, Inadequacies, Investigation, Crushing Strength, Box Shear.

I. INTRODUCTION

A rational approach for Analysis of Failure is to consider the sources of the problems and the symptoms together. Intrinsic and extrinsic causes of failures are needs to be study in depth for analysis and rehabilitation of the structure. Analysis of failure shall be carried out systematically in stages such as preliminary study & visual observations of structure and records, Field and laboratory tests, NDT tests on existing structure, use of suitable computer aided structural analysis software. This followed with interpretation and evaluation of test results data to design & plan most appropriate rehabilitation technique.

Rehabilitation of concrete structure to Original and / or intended Service Level may be classified under following cases:

Case 1) Aging, weathering, or deteriorating due to adverse environmental conditions

Case 2) Inadequacies in the design and detailing and defects during construction

Case 3) Damages due to external causes like accident, earthquake, floods, fire, etc. and foundation settlement,

Rehabilitation of structure to cater change in live load pattern during intended Service

Case 4) Increase in load carrying capacity or functional requirements

Inadequacies In The Design And Detailing And Defects During Construction:-

Construction defects are always key concern**(1)** to affect the performance of a structure can be the result of defective design or construction, defects that allow ground water intrusion into the structure and defects that will render the structure structurally unsound. In general, examples of these defects are: A design that fails to meet the Professional Standard of Care. A design that was not prepared in accordance with the applicable building codes. The failure of the contractor to execute the work in accordance with the plans and specifications. The failure of the contractor to execute the work in accordance with the acceptable standards of workmanship in the construction industry. The improper installation of systems, equipment's or materials that are of a lesser quality than required by the plans and specifications.

A construction defect is generally defined as a defect or deficiency in the design, the construction, and/or in the materials or systems used on a project that may not be readily observable and results in a structure or component that is not suitable for the purpose intended. Therefore, the term "construction defect's broader than just defective construction. The term "construction defect'' includes both design and construction defects that result in financial harm to the owner.

Causes of Construction Defects:-

Design defects have become prevalent as a result of the trend to abandon the traditional design approach where the architect would utilize established architectural standards and details for the construction of a building that were similar and consistent, i.e. "tried and true". The introduction of computer-aided design ("CAD")with its dependence on stock details, coupled with the rapidly evolving new building materials and systems has had a dramatic impact on the design and construction detailing of new buildings and has greatly increased the potential for defective design. The new materials and systems, many of them untested over time, have limited applications and in many cases are not ideally suited for a particular application, building type and/or geographic location. Architects, in lieu of employing time-tested materials and assemblies, rely on the information, literature and details supplied by the manufacture for the new materials and/or assemblies without a full understanding these limitations and the proper application of the new materials and systems. The vast array of new materials and systems has played a critical role in the increase in design defects claims. Architects also have tended to reduce the level of details they provide in the design and construction documents in a conscious and misguided effort to leave the construction detailing to the imagination and creativity of the contractor. This lack of adequate detailing may also be due to the lack of experience and understanding by the architect of the basics of a particular assembly and/or material.

The incidence of construction defects has increased due to a fundamental change in the role of the contractor. The "Master Builder" has become the master broker whose goal of low initial cost and higher profits has overridden the goal of providing a defect-free product. Speed and profit have become the contractor's primary considerations and goals. [(2)]

II. LITERATURE REVIEW

E.H.Davis, F.I.E. and H.G. Poulos

In this paper they designed the foundation for a large building on a deep deposit of clay; it may be found that a raft foundation would have an adequate factor of safety against ultimate bearing capacity failure but that the settlement would be excessive. Normal practice (assuming the addition of basements to produce a floating foundation is unacceptable) would then be to pile the foundation, the number of piles being chosen to give an adequate factor of safety against individual pile failure and assuming the piles take the entire load. However, it is clearly illogical to design the piles on an ultimate load basis when they have only been introduced in order to reduce the settlement of an otherwise satisfactory raft. A method of analysing such pile-raft systems, and of determining the required number of piles to reduce the settlement to the required amount. [(3)]

V. Balakumar, K. Ilamparuthi

In this paper they proposed that Piled raft foundation system is increasingly becoming an alternate to deep piles in the case of structures with raft, when raft alone cannot satisfy the settlement requirement. Among the various structures, storage tanks are more sensitive for settlements. Hence the piled raft can become a viable alternate system, when the raft (which forms the base of the tank) is seated on a favourable ground from bearing capacity point of view. For such cases the design economy depends upon the optimized pile design. The layout and the configuration become very important to produce the desired settlement reduction and load sharing with minimum required piles. This paper presents the effect of pile configuration and the pile raft area ratio on the behaviour of piled raft on sand based on the results of 1g model studies.[(4)]

Ascalew Abebe & Dr Ian GN Smith

In this paper they proposed that dealing with geotechnical and ground engineering techniques classify piles in a number of ways. The objective of this unit is that in order to help the undergraduate student understand these classifications using materials extracted from several sources. [(5)]

III. RECONNAISSANCE SURVEY AND ANALYSIS

About the project:-

Major underground water leakage though raft foundation at basement of Beach Resorts in Goa was leant in September 2015. When contacted to understand about the site, the General Manager, of Resort has informed that the construction of the Resort was completed in year 2001 (Fig 1).

The subject building has basement, Ground and first floor. The basement of the building was being used as a Conference hall, administrative offices, Maintenance and House Keeping Sections for during last 10-11 years. However, in year 2010, the Conference Hall area of the basement floor started showing dampness (Fig 2), which further deteriorated years ahead.

The major leakage through basement floor commenced from year 2014. This has resulted in water pool up to the height of 1 ft in the basement during last two monsoons (Fig 3). As such, the basement floor became obsolete functionally. RCC raft treated with injection grout and waterproofing treatment in 2014(Fig 4).

Fig 1 Photo showing the building at the resort & access to the basement

Fig 2 The basement passage started showing ground water dampness in 2010

Fig 3 Ground water table up to depth of 1 ft. in year 2014 monsoon

Fig 4 RCC raft treated with injection grout and waterproofing treatment in 2014.

In year 2015, the site conditions was further deteriorated when underground water fountain out up to the height of 900 mm (Fig 5)

Fig 5 Underground water fountain out up to the height of 900 mm in Sept' 2015

In October 2015, Beach Resort has called for structural rehabilitation of the basement foundation. As a post-graduate student and the thesis project work, I have approached Resort with the written request to allow to carry out in-depth site investigation, review and interpret all available details, sub-soil investigation, analysis of existing structure and causes for the failure of basement raft and to propose rehabilitation scheme of the basement foundation. Beach Resort had given the consent to carry out this assignment under the direction of Project Management Consultant (PMC), which is already appointed. PMC has also given consent to this project assignment, which is to be carried out by me independently with the pre-condition that the approval shall be obtained for each & every step being performed by me.

Reconnaissance Survey and Site Investigation:-

Upon receipt of the Thesis Work Acceptance Letter, the reconnaissance survey and site investigation was commenced immediately with the line of action as mentioned below:

1. Assessment of As Built Drawings - Structural & Architectural drawings etc., Construction Reports etc. available with Beach Resort. Interrogation with the senior staff of Hotel and the contractor's engineer/ supervisor who carried out the basement raft work in year 2010.
2. Concrete Core cutter through existing raft.
3. Inspection pit through RCC basement raft.
4. Bore-logs for Sub-soil investigation and to ascertain individual footings.
5. Maximum ground water table.
6. Laboratory Testing to get design parameters.

1. Assessment of As Built Drawings:-
Structural & Architectural drawings etc., Construction Reports etc. available with Hotel. Interrogation with the senior staff of Hotel and the contractor's Engineer/ supervisor who carried out the basement raft work in year 2010.

1) As Built Drawings & Construction Report: Not available with Hotel.

a. List of the Working drawings available: Foundation Plan & Details Drg. No. WS/S-01C dated 19/5/2005.

2) In absence of As Built Drawings, the raft foundation elements narrated by the Contractor's engineer (Presently in Bihar) during telephonic discussion in Oct 2015.as sketched in fig 6.

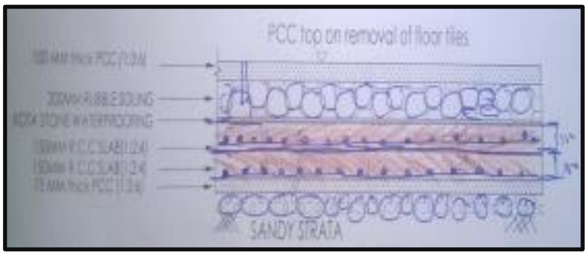

Fig.6 Sectional elements of Foundation as briefed by contractors engineer during telephonic discussion

3) In absence of As Built Drawings, Mr. Shahabuddin, Contractor's supervisor was interrogated to ascertain the foundation aspects. (Attended the site inspection dated 3rd November 2015). The details narrated are presented in sketch no. Fig 7.

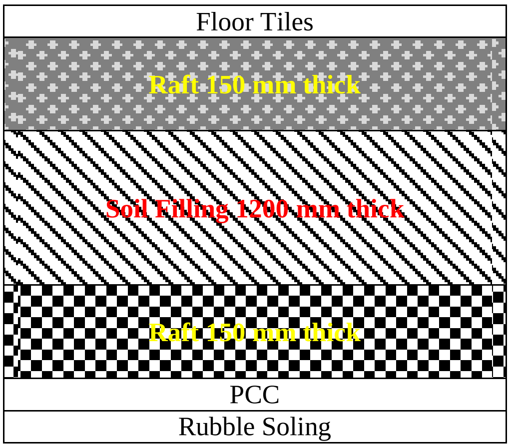

Fig 7 Sectional Details of Foundation as briefed by Shahabuddin, Contractor's supervisor during construction in year 2010

Comments: In absence of As Built Drawings of foundations and with differing statements from the ex-site engineer and the supervisor, it was decided to carry out concrete core cutter and trial pit through existing raft foundation.

2. Concrete Core Cutter through Existing Raft (A):-

Fig 8 Concrete core from existing raft slab

3. Inspection Pit through RCC Basement Raft.
The sectional details of the trench (Trial pit) for the inspection purpose.

Fig 9 Inspection of open trench made in raft

Fig 10 Raft sectional details noted from open trench

The trial pit made in the existing raft to get the sectional details of the existing RCC raft. The observations made by me are tabulated below,

OBSERVATIONS

Inspection of open trench made in RCC raft to obtain As Built Sectional details	
PCC(Top layer) =	120 mm
Cuddapa stone waterproofing=	30mm
RCC raft =	150 ± 25 mm
	8 mm dia tor @ 300 mm c/c both ways
Three layer stone water proofing =	70 mm
PCC=	75 mm
Laterite rubble soling (Bottom)	100 mm
Grade of Concrete : Doubtful – need to ascertain	

Table no 1 Observation noted from open trench

Subsequently, WPBR has provided with few RCC drawings of the foundation with no confirmation about its significance as “As Built Drawing” Or “Working Drawing”.

Details as per RCC drawing available with the Client
Individual Footing : Trapezoidal Size 3600 x 3600 with D =700 MM & d=250 mm RCC Raft thickness – 250 mm Reinforcement in raft : 10 mm @ 150 mm c/c Both ways Grade of Concrete as per drg: M20

Table no 2 Observation noted from RCC Drawings

DESCRIPTION	AS PER AVAILABLE DRAWINGS	ON SITE OBSERVATION OF OPEN TRENCH
Thickness/Depth of existing raft slab	250 mm	150 ± 25 mm
Steel diameter	10 mm	8 mm
Spacing of steel	150 mm (Both ways)	250 – 300 mm (Both ways)
Concrete grade	M 20	M 30 (Concrete Core samples tested in laboratory)

Table no 3 Comparison between existing drawings and on site observation of open trench

1. Comments:RCC raft slab sectional details observed on site differ from the relevant RCC drawing.
2. Further, reinforcement steel in existing RCC raft is much less than nominal steel of 0.2% required in reinforced concrete as per IS 456-2000[(B)].
3. Therefore, raft failure may be the case of defect in construction. As such, it is decided to discard existing RCC raft and rehabilitate the basement raft by introduction of new RCC raft with micro piles.

Pursuant to above conclusion, it was decided to carry out bore-log near 4 main columns to ascertain individual footings of these columns and the separate bore- log for sub-soil investigation of un-disturbed strata.

4. Bore-Log for Sub-Soil Investigation & to ascertain individual footings:-

To find out the type of strata/Soil below the existing raft, the extraction of samples were necessary by UD (Undisturbed) sample test.

Fig 11 Marking (75mm) on the sample extraction pipe/tube from that height weight has to be released

Fig 12 Marking on the SPT tube (150 mm)

Fig 13 Release of weight for the extraction of soil sample

Fig 14 Soil extraction pipe/tube (Soil sampler tube)

Fig 15 Extracted soil sample at the depth of 1.53-1.98 mt

Fig 16 Extracted soil sample at the depth of 4.05-4.40 mt

Comments:

1) From bore log exploration, it is observed that columns have individual footings to disperse building load to suitable strata below basement level. RCC raft at basement level forms a structural member to sustain uplift of underground water of head 2m
2) Concrete core from RCC raft and soil samples obtained from bore logs were tested in Civil Engineering laboratory of Govt. College of Engineering, Goa

5. Maximum Ground Water Table:-

Maximum level of ground water table remains 2 mt above basement slab of conference area. These details were obtained from engineering section of WPBR as well as interrogation with WPBR staff. The details so obtained were also verified by inspection of open well near to the building.

Laboratory Testing and Results for Different Tests:-

1) Crushing Strength of Concrete Core of existing Raft [(6) (C)]: - A compression test is a method for determining the behaviour of materials under a compressive load. Compression tests are conducted by loading the test specimen between two plates and then applying a force to the specimen by moving the crossheads together. The compression test is used to determine elastic limit, proportionality limit, yield point, yield strength and compressive strength.

Procedure:-

1. Dimensions of test piece is measured at 3 different places along its height/length to
2. determine the average c/s area.
3. Ends of the specimen should be plane. For that the ends are tested on a bearing plate.
4. The specimen is placed centrally between the two compression plates, such that the

5. centre of moving head is vertically above the centre of specimen.
6. Load is applied on the specimen by moving the movable head.
7. The load and the corresponding contraction are measured at different intervals.
8. Load is applied until the specimen fails.

Fig 17 Placing the concrete core of existing RCC raft

Fig 18 Application of the load

Fig 19 Maximum loading on the concrete core

Fig 20 Failure of concrete core

Table no 4 Compression test on the concrete core from existing raft (Refer Fig 21)

Sr no	Description	Size of the core		Load in kN	Strength in N/mm2
		Ht. in mm	Dia. in mm		
1	Cylinder 1	200	120	349.7	30.94
2	Cylinder 2	200	120	267.3	23.65
3	Cylinder 3	200	120	394.7	34.89
4	Cylinder 4	200	120	321.8	28.45
5	Cylinder 5	200	120	347.4	30.71
6	Cylinder 6	200	120	341.0	30.15

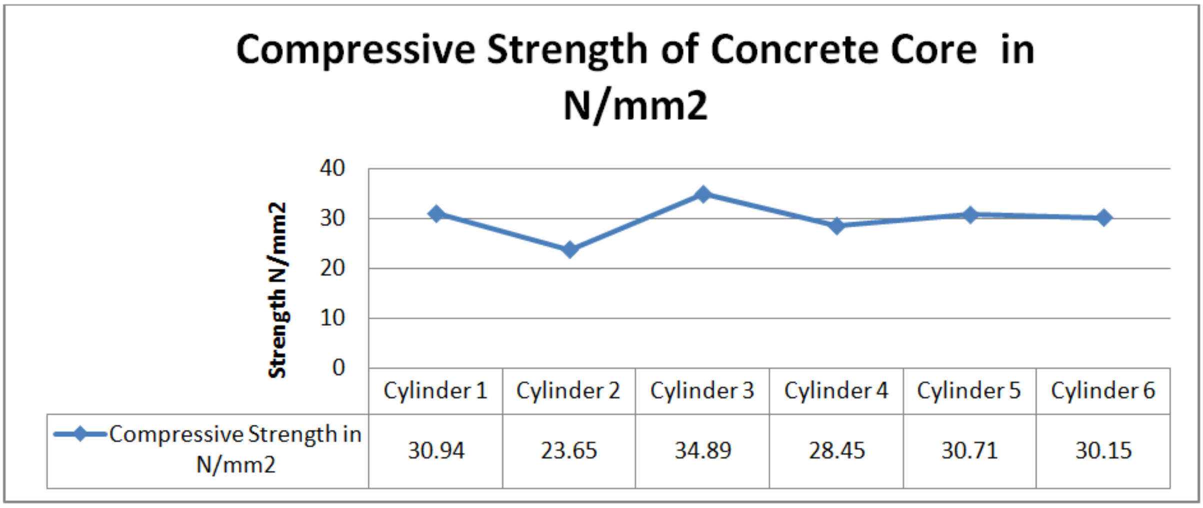

Fig 21 Graph showing the compressive strength of concrete core

2) Box Shear Test (Direct Shear) [(7) (D)]:-

A direct shear test is a laboratory or field test used by geotechnical engineering to measure the shear strength properties of soils or rock material, or of discontinuities in soil or rock masses. The test is performed on two or three specimens from a relatively undisturbed soil sample. A specimen is placed in a shear box which has two stacked rings to hold the sample; the contact between the two rings is at approximately the mid-height of the sample.A confining stress is applied vertically to the specimen, and the upper ring is pulled laterally until the sample fails, or through a specified strain. The load applied and the strain induced is recorded at frequent intervals to determine a stress-strain curve for each confining stress. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion (c) and the angle of internal friction, commonly known as friction angle (Φ). The results of the tests on each specimen are plotted on a graph with the peak (or residual) stress on the y-axis and the confining stress on the x-axis. The y-intercept of the curve which fits the test results is the cohesion, and the slope of the line or curve is the friction angle.

Direct shear tests can be performed under several conditions. The sample is normally saturated before the test is run, but can be run at the in-situ moisture content. The rate of strain can be varied to create a test of undrained or drained conditions, depending whether the strain is applied slowly enough for water in the sample to prevent pore-water pressure build-up. Direct shear test machine is required to perform the test. The test using the direct shear machine determinates the consolidated drained shear strength of a soil material in direct shear.

The advantages of the direct shear test over other shear tests are the simplicity of setup and equipment used, and the ability to test under differing saturation, drainage, and consolidation conditions. These advantages have to be weighed against the difficulty of measuring pore-water pressure when testing in undrained conditions, and possible spuriously high results from forcing the failure plane to occur in a specific location.

Procedure:-

1) Check the inner dimension of the soil container.
2) Put the parts of the soil container together.
3) Calculate the volume of the container. Weigh the container.
4) Place the soil in smooth layers (approximately 10 mm thick). If a dense sample is desired tamp the soil.
5) Weigh the soil container, the difference of these two is the weight of the soil. Calculate the density of the soil.
6) Make the surface of the soil plane.
7) Put the upper grating on stone and loading block on top of soil.
8) Measure the thickness of soil specimen.
9) Apply the desired normal load.
10) Remove the shear pin.
11) Attach the dial gauge which measures the change of volume.
12) Record the initial reading of the dial gauge and calibration values.
13) Before proceeding to test check all adjustments to see that there is no connection between two parts except sand/soil.
14) Start the motor. Take the reading of the shear force and record the reading.
15) Take volume change readings till failure.
16) Add 5 kg normal stress 0.5 kg/cm2 and continue the experiment till failure.
17) Record carefully all the readings. Set the dial gauges zero, before starting the experiment.

Fig.22 Recording the readings from the dial gauges

Results:-

Size of sample: - 60 mm X 60 mm X 25 mm
Area of sample: - 36 Sq.cm
Proving ring constant (Kg/div):- 0.32

Horizontal Dial Reading (div.)	**Shear Force (Kg)**	**Shear Stress (Kg/cm^2)**	**Normal Stress (Kg/cm^2)**
12	3.84	0.106	0.2
38	12.16	0.33	0.4
63	20.16	0.56	0.7

Table no 5 Readings of Box Shear Test

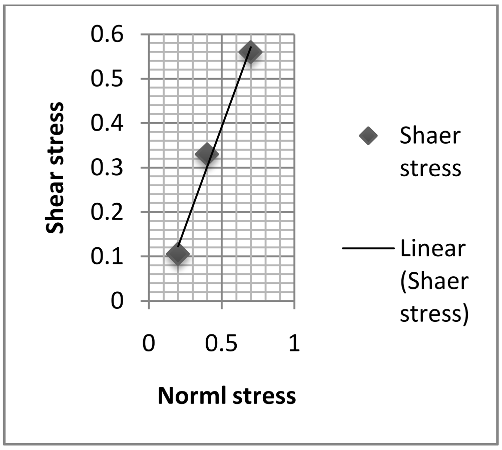

Fig.23 Graph showing reading of shear stress vs. normal stress

From the graph plotted by using the shear stress vs. normal stress we got the value of,
C = 0
Ø = 37 deg

4. Computer aided software (STAAD Pro) to check design of the existing raft slab [(8)]: - To check the design of existing raft slab, which has been submitted as per the working drawing of Delhi based consultant, need to be ascertain by using computer aided software (i.e. STAAD Pro), so as to understand the type of failure of structure (i.e. Due to design failure or due to the construction failure).

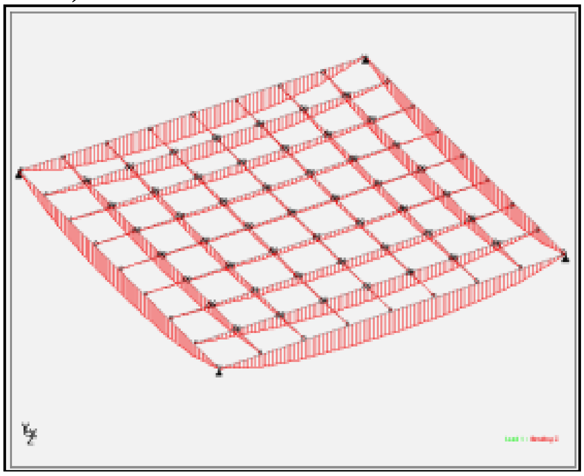

Fig.24 STAAD Pro Analysis for Shear and Bending

Beam End Force Summary

The signs of the forces at end B of each beam have been reversed. For example: this means that the Min Fx entry gives the largest tension value for an beam.

				Axial	Shear		Torsion	Bending	
	Beam	Node	L/C	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	1	1	1:LOAD CASE	**0.000**	26.000	0.000	0.000	0.000	0.000
Min Fx	1	1	1:LOAD CASE	**0.000**	26.000	0.000	0.000	0.000	0.000
Max Fy	17	9	1:LOAD CASE	0.000	**26.000**	0.000	0.000	0.000	0.000
Min Fy	136	81	1:LOAD CASE	0.000	**-26.000**	0.000	0.000	0.000	0.000
Max Fz	1	1	1:LOAD CASE	0.000	26.000	**0.000**	0.000	0.000	0.000
Min Fz	1	1	1:LOAD CASE	0.000	26.000	**0.000**	0.000	0.000	0.000
Max Mx	18	8	1:LOAD CASE	0.000	12.909	0.000	**0.000**	0.000	0.000
Min Mx	60	28	1:LOAD CASE	0.000	1.915	0.000	**-0.000**	0.000	-42.740
Max My	1	1	1:LOAD CASE	0.000	26.000	0.000	0.000	**0.000**	0.000
Min My	1	1	1:LOAD CASE	0.000	26.000	0.000	0.000	**0.000**	0.000
Max Mz	52	28	1:LOAD CASE	0.000	2.953	0.000	0.000	0.000	**0.000**
Min Mz	68	45	1:LOAD CASE	0.000	1.103	0.000	0.000	0.000	**-44.249**

Fig.25 Beam end force summary from STAAD Pro.

IV. CONCLUSION

1) Holistic approach to study intrinsic and extrinsic causes of failures of structure is indispensable for methodical analysis of the failed structure, before confirming rehabilitation design.
2) Inadequate structural analysis and design forms focal cause of structural failure. However, Defects during construction, viz not to adopt approved RCC working drawing or inappropriate Work Methodology or lack of engineering supervisions & ineffective quality control equally forms one of the major cause of failure of structure.
3) The actual case study under deliberation is the best example of structural failure RCC raft due to defects during construction, which are owing to:
   a. Indiscreet approach not to adopt approved RCC working drawings,
   b. Inappropriate work methodology
   c. Lack of engineering supervision
   d. Ineffective quality control

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CODES

(A) **IS 13311.1992** – Method of Non-Destructive testing of concrete

(B) **IS 456: 2000** – Plain and Reinforced Concrete Code of Practice

(C) **IS 516:1959 –** Method of tests for strength of concrete

(D) **IS 2720-13 (1986)** – Methods of tests for soils, part 13: Direct shear test