DESIGN OF RC CANTILEVER RETAINING WALL UNDER EARTHQUAKE CONDITIONS

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY
IN
STRUCTURAL ENGINEERING

Submitted by

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MTech (Structural Engineering) **RITIK SAHLOT** **2025**

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CANDIDATE'S DECLARATION

I, RITIK SAHLOT, 2K23/STE/15, of MTech (Structural Engineering), hereby declare that the project Dissertation titled "**Design of RC Cantilever Retaining wall under earthquake conditions**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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Signature of supervisor **Signature of Examiner**

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Design of RC Cantilever Retaining wall under earthquake conditions**" which is submitted by RITIK SAHLOT, 2K23/STE/15, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

This investigation here gives us the analysis about the Retaining wall which is presents a comprehensive analysis and design methodology for reinforced concrete (RC) cantilever retaining walls subjected to earthquake conditions. Retaining walls are essential for slope stability and earth retention, especially in hilly or seismically active regions. The study integrates both manual and software-based approaches for analyzing wall stability under combined static and seismic loads.

A Review of Research paper related to the design of RC Cantilever Retaining walls have been have also studied to get a deep insight analysis of the behavior of walls and also how to identify their interaction during the earthquake conditions.

The methodology includes use of Excel for design calculations and STAAD Pro for finite element modeling. The wall design accounts for various load combinations including self-weight, backfill pressure, surcharge, and seismic forces as per IS 1893:2016. Earthquake effects are considered using Mononobe-Okabe theory for lateral earth pressures.

There is also proper explanation of the staad file explaining the detailed material properties and load combinations acting on the structure and the result thereof.

Results indicate that appropriate detailing and design consideration for seismic loads significantly improves performance. Every check has been performed for the structure stability and the design is than performed.

The report concludes with recommendations for practical implementation and highlights the potential for future research in soil-structure interaction and time-history dynamic analysis and tells about the future scope which can be taken into account for making retaining walls more secure and safe.

The references have also been attached for future references and studies to be performed.

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RITIK SAHLOT

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LIST OF SYMBOLS AND ABBREVATIONS

Symbol/Abbreviation	Description
RC	Reinforced Concrete
FOS	Factor of Safety
DL	Dead Load
LL	Live Load
EQ	Earthquake Load
EP	Earth Pressure
SBC	Safe Bearing Capacity
Ld	Development Length
φ (phi)	Angle of internal friction of soil
δ (delta)	Wall-soil friction angle
γ (gamma)	Unit weight of soil (kN/m³)
H	Height of retaining wall (m)
Ka	Coefficient of active earth pressure
Kae	Seismic active earth pressure coefficient
Kh	Horizontal seismic coefficient
Kv	Vertical seismic coefficient
θ (theta)	Seismic inertial angle
R	Response Reduction Factor
I	Importance Factor
Z	Seismic Zone Factor (from IS 1893)
Sa/g	Spectral Acceleration Coefficient
E	Modulus of Elasticity
PR	Pressure (used in STAAD for load direction)
M	Moment (kNm)
V	Shear Force (kN)
Ast	Area of Steel Provided (mm²)
M30	Grade of Concrete (fck = 30 MPa)
Fe500	Grade of Reinforcement Steel (fy = 500 MPa)
FEM	Finite Element Method
SSI	Soil-Structure Interaction
STAAD.Pro	Structural Analysis and Design software by Bentley
IS	Indian Standard (code)
RCDC	Reinforced Concrete Design and Detailing software
FS	Factor of Safety
DAMP	Damping Ratio

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Retaining walls are essential structures in civil engineering, designed to support soil laterally and prevent slope failure. Among various types, Reinforced concrete (RC) cantilever retaining walls are widely used due to their cost-effectiveness, structural efficiency, and ease of construction. However, in seismic-prone regions, these walls are subjected to significant dynamic forces, making their design under earthquake conditions a critical aspect of geotechnical and structural engineering.

The performance of RC cantilever retaining walls during earthquakes is influenced by several factors, including seismic loading, wall geometry, soil-structure interaction, and foundation stability. Traditional design methods primarily focus on static conditions, but under seismic events, additional considerations such as dynamic earth pressures, inertia forces, and potential liquefaction effects must be addressed to ensure structural integrity and safety.

This thesis aims to analyze and optimize the design of RC cantilever retaining walls under earthquake conditions. It explores various analytical approaches, including pseudo-static and dynamic methods, to evaluate the impact of seismic forces. Additionally, numerical modeling and design optimization techniques will be utilized to enhance the performance and reliability of these structures. The study seeks to develop a comprehensive design framework that integrates seismic considerations, ensuring that RC cantilever retaining walls can withstand earthquake-induced stresses while maintaining cost-effectiveness and constructability

1.2 OBJECTIVES OF THE STUDY

Primary objectives of this study focus on:

- Studying various retaining wall and their behaviour under earthquake conditions
- Developing an excel program for designing the retaining wall
- Working on Staadpro and analysing the earthquake effects on retaining wall
- Providing a study analysis of retaining wall and its design.

1.3 OVERVIEW OF THESIS

CHAPTER 1- Provides the introduction of the topic and its approach.
CHAPTER 2- Discuss the literature review and the research gaps .
CHAPTER 3- Gives detailed explanation of the the methodology and the work carried out
CHAPTER 4-Discuss the results related to the working and explains the overall study.
CHAPTER 5- Provides the conclusion and future scope.

CHAPTER 2
LITERATURE REVIEW

The design of reinforced concrete (RC) cantilever retaining walls under seismic conditions has been extensively studied due to their critical role in infrastructure stability. Various researchers have explored analytical, numerical, and experimental methods to enhance the seismic performance of these structures. This section presents a review of ten significant studies on the topic.

Sitar et al.(2013) investigated seismic earth pressures acting on retaining walls using theories such as the Mononoke-Okabe method. This method provides a pseudo-static approach to estimating active and passive earth pressures under dynamic conditions. Recent studies have refined these models by incorporating soil nonlinearity and dynamic soil-wall interaction effects.

Simonelli et al. (2020) carried out experimental studies using shake table tests have revealed that the dynamic response of RC cantilever retaining walls depends on wall flexibility, backfill properties, and seismic input characteristics. Some studies have highlighted that rigid walls experience higher seismic forces, whereas flexible walls may exhibit lower earth pressures due to soil-structure interaction effects.

Cattoni et al. (2018) provided numerical simulations using finite element methods (FEM) have been widely used to analyze the behavior of retaining walls under earthquake loading. Studies have demonstrated that incorporating advanced material models and boundary conditions improves the accuracy of seismic response predictions, leading to better design recommendations.

Mylonakis et al. (2021) analyzed the role of soil-structure interaction (SSI) in the seismic behavior of retaining walls has been extensively studied. Research indicates that considering SSI leads to a more realistic estimation of seismic forces and wall displacements. Some studies have suggested using coupled soil-structure models to enhance seismic design accuracy.

Ahmed Mujtaba et al. (2017) provided that stability against sliding and overturning is a critical factor in designing RC cantilever retaining walls under seismic conditions. Research has shown that incorporating shear keys, increasing base friction, and optimizing wall geometry can significantly improve resistance against failure modes induced by seismic forces.

Hatami, K et al. (2007) has shown that the mechanical properties of both the retaining wall and the backfill material significantly impact seismic performance. Using lightweight backfill materials or geosynthetic reinforcement has been proposed as an effective strategy to reduce seismic forces acting on the wall.

Choi, J et al. (2017) showed that recent advancements in performance-based seismic design have provided new insights into optimizing retaining walls under earthquake conditions. Studies have suggested that designing for controlled deformation rather than excessive strength can lead to more efficient and economical solutions.

Nimbalkar, S et al. (2006) have compared pseudo-static and dynamic analysis methods for designing retaining walls under seismic conditions. Findings suggest that pseudo-static methods provide conservative estimates, whereas dynamic analyses offer a more realistic representation of wall behavior under earthquake loading.

Federal Emergency Management Agency (FEMA). (2006) made research and has also focused on retrofitting techniques for existing retaining walls in seismic regions. Strengthening strategies such as the addition of tie-backs, soil nailing, and base isolation have been proposed to enhance seismic resilience.

MDPI. (2023) carried out studies on past earthquake-induced retaining wall failures which have provided valuable insights into common failure mechanisms, including excessive displacement, cracking, and overturning. These case studies have contributed to the development of improved seismic design guidelines and construction practices.

This literature review highlights the significant contributions of past research in understanding and improving the seismic performance of RC cantilever retaining walls. The findings from these studies provide a foundation for further research into optimizing design methodologies to enhance safety and efficiency in seismic-prone region.

2.1 RESEARCH GAP

Research Gaps in the Design of RC Cantilever Retaining Walls Under Earthquake Conditions

Based on the reviewed literature, several research gaps exist in the seismic design of RC cantilever retaining walls. Identifying these gaps is essential for advancing current design methodologies and improving the seismic resilience of such structures.

Despite significant progress in geotechnical and structural engineering, there are still a number of unsolved issues with the seismic design of reinforced concrete (RC) cantilever retaining walls. The extensive use of the Mononobe-Okabe (M-O) method, a pseudo-static technique that calculates seismic ground pressures using oversimplified assumptions, is a notable drawback of contemporary design techniques. Although the M-O technique offers a useful approximation, it ignores how earthquake loading is dynamic and time-dependent. It can result in erroneous estimates of seismic demands because it ignores important factors including wall deformations, seismic wave propagation, and transient soil behaviour. The creation of more precise dynamic analysis models that can replicate real-time earthquake effects is therefore urgently needed.

The problem of soil-structure interaction (SSI), which has a big impact on how well retaining walls function under seismic loads, is closely tied to this. Although the literature acknowledges the influence of SSI, it is frequently addressed using too simplistic models that disregard the coupled interaction between the wall and backfill or assume linear behaviour. Predicting displacement patterns, the distribution of ground pressure, and possible collapse processes can all be inaccurately affected by such simplifications. In order to guarantee model correctness and practicality, future studies should concentrate on sophisticated numerical modelling approaches that reflect nonlinear SSI behaviour and are backed by experimental validation.

Climate change may alter soil properties and groundwater levels, which can affect seismic responses. However, most studies do not consider these evolving environmental factors. Future research should explore the impact of climate change on soil behaviour, pore water pressure changes, and their influence on seismic retaining wall performance.

Analytical and numerical models must be experimentally validated in order for design techniques to be considered credible. However, small-scale shake table or centrifuge models—which are limited by scaling effects and might not adequately represent behaviour in the actual world—are used in the majority of current experimental studies on retaining walls. These restrictions include differences in boundary conditions, material nonlinearity, and stress distribution. To test and calibrate numerical models and improve the reliability of seismic design methodologies, full-scale practical research under seismic circumstances is desperately needed.

In conclusion, there are a number of important research gaps in the areas of modelling, experimentation, materials, and design philosophy related to the seismic design of RC cantilever retaining walls. It will be crucial to address these problems through thorough, multidisciplinary research in order to improve design procedures and guarantee the long-term safety and resilience of these vital infrastructure elements.

CHAPTER 3
METHODOLOGY

3.1 DESIGNING THROUGH EXCEL PROGRAMMING

The Design of a Reinforced Concrete (RC) cantilever retaining wall under earthquake conditions involves a systematic approach that integrates geotechnical, structural, seismic design principles, details the logic and structure of the Excel-based program developed to design RC cantilever retaining walls under seismic conditions. The tool integrates geotechnical inputs, stability checks, and structural design of the wall components in a step-by-step format.

- Sliding,
- Overturning
- Bearing

Determining structural detailing for various wall components

- Heel
- Toe
- Key
- Stem

3.1.1 DATA COLLECTION AND ASSUMPTIONS

Input parameters used in the design were gathered from project-specific site conditions and standard design codes (IS 456:2000, IS 1893:2016, IS 3370, etc.). The following assumptions and parameters were used

- Soil unit weight: 20 kN/m³
- Angle of internal friction (φ): 30°
- Concrete grade: M30
- Steel grade: Fe500
- Coefficient of friction at base: 0.5
- Earthquake parameters derived from IS 1893:2016 using response spectra for site location
    - Seismic zone: Zone IV (Z = 0.24)
    - - Importance factor (I): 1.5
    - - Response reduction factor (R): 3

- Wall types: Type 1 to Type 10 (based on height and backfill configurations)

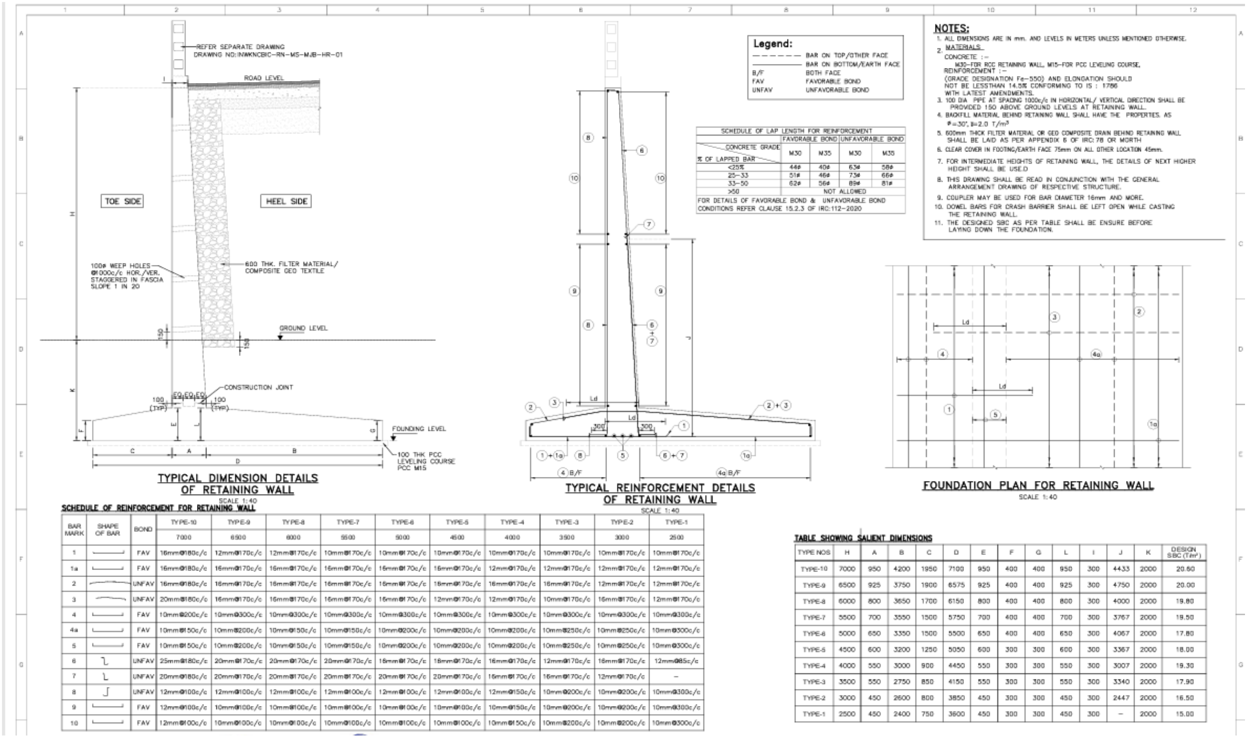


Figure 3.1 DATA AND WALL TYPES

3.1.2 EARTH PRESSURE AND LOAD CONSIDERATION

The earth pressure behind the wall is computed using:

- Rankine theory for static conditions

- Mononobe-Okabe method for seismic conditions

Active earth pressure coefficient, Ka (Rankine): $Ka = \tan^2(45 - \varphi/2) \approx 0.33$

Seismic increment, $\Delta Kae = (Kh * (1 - Ka))$ (simplified)

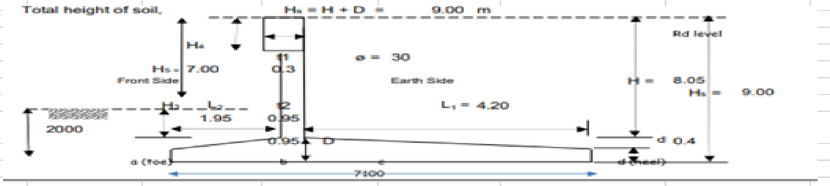
Total pressure = $\gamma * H * Ka + q * Ka$ + seismic increment

- Self-weight of wall
- Earth pressure (static and seismic)
- Live load surcharge (uniform)
- Backfill pressure

STABILITY CHECK FOR TYPE 10 WALL

`	VALUES
H	7
A	0.95
B	4.2
C	1.95
D	7.1
E	0.95
F	0.4
G	0.4
L	0.95
I	0.3
J	4.433
K	2

ANGLE(Ø)=	30	ANGLE(δ)=	20	SESIMIC HORIZONTAL COEFFICENT	0.1
UNIT WEIGHT of soil=	20	COCNCRETE GRADE	30	SESIMIC VERTICAL COEFFICIENT	0.05
COEFFICENT OF FRICTION	0.5	XUL/D	0.46	SESIMIC EARTH PRESSURE COEFFICENT	1.594
DENSITY OF CONCRETE	25	STEEL GRADE	500	BASE SHEAR LOAD	781



DESCRIPTION OF MEMBER	AREA	MAGNITUDE	CG DISATNCE	MOMENT	ACTIVE EARTH PRESSURE COEFFICIENT	ACTIVE EARTH PRESSURE	STABILIZING MOMENT	OVERTURNING MOMENT
RECTANGULAR PORTION OF WALL	2.415	60.375	2.1	126.7875	0.28	226.8	4423.005938	2695.056
TRAINGULAR PAORTION OF WALL	2.61625	65.40625	2.466666667	161.3354167	0.312			
SOIL ON HEEL TRAINGULAR SIDE	2.795	55.9	2.683333333	149.9983333				
TOE BACKFILL	2.58375	51.675	0.90754717	46.8975				
SOIL ON HEEL TRAPEZOIDAL SIDE	34.965	699.3	5.023123123	3512.67				
FOOTING(TRAPEZOIDAL PART LEFT)	1.31625	32.90625	1.107407407	36.440625				
FOOTING(TRAPEZOIDAL PART RIGHT)	2.835	70.875	4.714814815	334.1625				
FOOTING(SQUARE PART)	0.9025	22.5625	2.425	54.7140625				
LL SURCHARGE	3.024	60.48	4.5	272.16				
SUM=		1059		4423.005938				

Figure 3.2 LOAD CALULATION

3.1.3 STRUCTURAL ANALYSIS AND STABILITY CHECK

Design moments and shear forces were computed for stem, heel, toe, and base slab. Structural checks included:

The following checks are performed:

- Overturning check: Moment of resisting forces > 1.5 × moment of driving forces
- Sliding check: Fs = Resisting force / Driving force; Fs > 1.5 (safe)
- Bearing pressure check: Must be less than SBC (Allowable bearing pressure)

➢ Overturning stability

	PARTIAL SAFETY FACTOR	Pmax	Unfactored			Factored		
			ML due to hl about the toe		ML due to P	Pmax	ML due to HL	ML due to P
		kN	kN-m		kN-m	kN	kN-m	kN-m
Earth Pressure	1	0	2422.896		0	0	2422.896	0
LL Surcharge	1	0	272.16		0	0	272.16	0
Weight of Subst	1	125.7813	0		288.1229167	125.78125	0	288.1229167
Weight of fdn	1	126.3438	0		425.3171875	126.34375	0	425.3171875
Backfill Wt.	1	806.875	0		3709.565833	806.875	0	3709.565833
						1059	2695.056	4423.005938

STABILIZING MOMENT =	4423.006
OVERTURNING MOMENT =	2695.056
CHECK FOR OVERTURNING =	1.641155485

Figure 3.3 OVERTURNING CHECK

➢ Sliding stability

	UNFACTORED(HL) ABOUT TOE	PARTIAL SAFETY FACTOR	Factored	UNFACTORED P	PARTIAL SAFETY FACTOR	FACTORED D P(min)
Earth Pressure	226.8	1	226.8	0	1.5	0
LL Surcharge	60.48	1	60.48	0	0.95	0
Weight of Substr.	0	1	0	125.78125	1	125.78125
Weight of fdn	0	1	0	126.34375	1	126.34375
Backfill Wt.	0	1	0	806.875	1	806.875
			287.28			1059
CHECK FOR SLIDING =		1.84315				

Figure 3.4 SLIDING CHECK

- Bearing capacity check

			Combination for Base Presure						
			Unfactored				FACTORED		
		PARTIAL SAFETY FACTOR	P	ML due to HL		ML due to P	P	ML due to HL	ML due to P
			kN	kN-m		kN-m	kN	kN-m	kN-m
Earth Pressure		1	0	2422.896		0	0	2422.896	0
LL Surcharge		1	0	272.16		0	0	272.16	0
Weight of Substr.		1	125.78125	0		288.1229167	125.78125	0	288.12292
Weight of fdn		1	126.34375	0		425.3171875	126.34375	0	425.31719
Backfill Wt.		1	806.875	0		3709.5658	806.875	0	3709.5658
							1059	2695.056	4423.0059

ECCENTRICITY	BASE PRESSURE MAX	BASE PRESSURE MINIMUM
1.918319228	390.9521995	-92.64234

Figure 3.5 BASE PRESSURE

3.1.4 DESIGN OF STRUCTURAL COMPONENTS

Each component of the retaining wall was designed individually:

- **Stem**: Designed as a vertical cantilever subjected to triangular earth pressure distribution. Reinforcement was provided accordingly.

DESIGN OF STEM

	UNFACTORED			PARTIAL SAFETY FACTOR	Factored		
	P	HL	ML		P	HL	ML
Earth	0	202.1838	683.5834278	1.5	0	303.2757	1025.375142
LL Surcharge	0	60.48	243.432	1.2	0	72.576	292.1184
Weight of Substr.	125.78125	0	0	1.35	169.804688	0	0
					169.8046875	375.8517	1317.49354

DESIGN FOR FLEXURE

DEPTH OF SECTION-	0.95		
CONSIDERING SECTION WIDTH AS	1		
DESIGN MOMENT PER WIDTH	1317.493542	AST REQUIRED-	4211
COVER	0.075		
PROVIDING STEEL OF DIA -	0.025	SPACING PROVIDED -	110
d provided	0.8625		
AST PROVIDED	4464.285714		
DISTRIBUTION REINFORCEMENT REQUIRED	842.2		
PROVIDING STEEL OF DIA -	0.01	SPACING PROVIDED -	90
AST PROVIDED	873.015873		

MIN Ast	1121.25	Ym	1.5
Moment of Resistance of (0.133*fck*b*d^2)	2968.185938	α	0.67
		fcd	13.4
Lever arm d*(1-0.974*fy*Ast/(fck*b*d))	790.0297619		
Moment of Resistance of (0.87*fy*As*Z)	1534.209582		

CHECK FOR SHEAR	
ULTIMATE VED	375.8517
STRENGTH REDUCTION FACTOR	0.541935484
MAX SHEAR	3131.709677
K	
AXIAL FORCE	0
SIGMA CP	0
ρl	0.005175983
Vrcd	0

Figure 3.6 STEM CALCULATION

AT STEM BOTTOM LEVEL (STRESS CHECK)							
	UNFACTORED			PARTIAL SAFETY FACTOR	Factored		
	P	HL	ML		P	HL	ML
Earth P	0	202.1838	683.5834278	1	0	202.1838	683.5834278
LL Surcharge	0	60.48	243.432	0.8	0	48.384	194.7456
Weight of Substr.	125.78125	0	0	1	125.78125	0	0
					125.78125	250.5678	878.3290278

AT STEM BOTTOM LEVEL(CRACK CHECK)							
	UNFACTORED			PARTIAL SAFETY FACTOR	Factored		
	P	HL	ML		P	HL	ML
Earth	0	202.1838	683.5834278	1	0	202.1838	683.5834278
LL Surcharge	0	60.48	243.432	0	0	0	0
Weight of Substr.	125.78125	0	0	1	125.78125	0	0
					125.78125	202.1838	683.5834278

STRESS CHECK			
DESIGN MOMENT	878.3290278		
SIGMA ST	400		
sigma ck'	14.4		
modular ratio	6.481481481		
steel percentage	0.517598344		
Depth of neutral axis	196.3433965		
lever arm	797.0522012		
effective cover provided	113	a	0.925
effective depth provided	0.8625	e1	0.001050677
Provided AST	4464.285714	e2	0
STRESS IN STEEL	246.8416773	e'	0.001050677
STRESS IN CONCRETE	11.22494357		

CRACK CHECK			
DESIGN MOMENT	683.5834278	φ	25
STRESS IN STEEL	192.1112414	hc	218.75
STRESS IN CONCRETE	8.736117289	ρ	0.020408163
AVERAGE STRAIN AT THE LEVEL	0.00105037	kt	0.5
DIAMETER CHECK	25	fct	2.5
SPACING CHECK	250	sr max	463.25
SR MAX	463.25	Es	200000
		Ec	31000
WK	0.284427915	σ	192.1112414
ALLOWABLE CRACK WIDTH	0.3	esm-ecm	0.000613984

Figure 3.7 STEM DESIGN AT BOTTOM LEVEL

DESIGN OF STEM CURTAILMENT							
MAXIMUM HEIGHT OF FILL ABOVE CURTAILMENT LEVEL				5.4			
	UNFACTORED			PARTIAL SAFETY FACTOR	Factored		
	P	HL	ML		P	HL	ML
EARTH PRESS	0	90.9792	206.3408256	1.5	0	136.4688	309.5112384
LL SURCHARGE	0	40.57043478	109.5401739	1.2	0	48.68452174	131.4482087
Weight of Substr.	0	0	0	1.35	0	0	0
					0	185.1533217	440.9594471

DESIGN FOR FLEXURE			
DEPTH OF SECTION-	0.69		
CONSIDERING SECTION WIDTH AS	1		
DESIGN MOMENT PER WIDTH	440.9594471	AST REQUIRED-	1658
COVER	0.075		
PROVIDING STEEL OF DIA -	0.025	PROVIDED -	250
d provided	0.6025		
AST PROVIDED	1964.285714		
DISTRIBUTION REINFORCEMENT REQUIRED	331.6		
PROVIDING STEEL OF DIA -	0.01	SPACING PROVIDED -	200
AST PROVIDED	392.8571429		

MIN Ast	783.25	Ym	1.5
Moment of Resistance of (0.133*fck*b*d^2)	1448.394938	α	0.67
		fcd	13.4
Lever arm d*(1-0.974*fy*Ast/(fck*b*d))	570.6130952		
Moment of Resistance of (0.87*fy*As*Z)	487.5685108		

CHECK FOR SHEAR	
ULTIMATE VED	185.1533217
STRENGTH REDUCTION FACTOR	0.541935484
MAX SHEAR	2187.658065
K	1.576151202
AXIAL FORCE	0
SIGMA CP	0
ρl	0.003260225
Vrcd	224.6868185

FOR STRESS CHECK							
	UNFACTORED			PARTIAL SAFETY FACTOR	Factored		
	P	HL	ML		P	HL	ML
EARTH PRESS	0	90.9792	206.3408256	1	0	90.9792	206.3408256
LL SURCHARGE	0	40.57043478	109.5401739	0.8	0	32.45635	87.63213913
Weight of Substr.	0	0	0	1	0	0	0
					0	123.4355478	293.9729647

Figure 3.8 STEM CURTAILMENT CALCULATION

- **Heel Slab**: Designed for upward soil reaction and downward weight of backfill and wall.

DESIGN OF HEEL SLAB								
GROSS PRESSURE	HEEL END	TOE END	A-A	B-B	At deff from A-A	At deff from B-B	MU AT AA	MU AT BB
COMB1	-163.465541	566.1838506	268.1580429	365.7871868	177.2087878	456.7364419	-172.7927333	949.4556602
COMB2	-179.157175	477.4670338	209.2684135	297.1265822	127.4215931	378.9734025	-438.1950515	793.4934368
RARE COMBINATION	-86.1636258	384.4734849	192.2414256	255.2139968	-	-	58.54767182	649.0620126
QUASI COMBINATION	-60.2487676	358.5586268	187.4964516	243.5340607	-	-	196.9768142	608.8127704

DEPTH OF HEEL AT EDGE	0.4	TOTAL WEIGHT	755.2
DEPTH OF HEEL AT STEM	0.95	TOTAL FACTORED WEIGHT	1019.52
WEIGTH OF HEEL	70.875		
CG OF LOAD FROM STEM	1.814814815		
CORRESPONDING STEM	128.625		
WEIGTH OF BACKFILL	755.2		
CORRESPONDING MOMENTS	1472.588333		
TOTAL MOMENTS	1601.213333		
TOTAL FACTORED MOMENTS	2161.638		

DESIGN FOR FLEXURE			
DEPTH OF SECTION-	0.95		
CONSIDERING SECTION WIDTH AS	1		
DESIGN MOMENT PER WIDTH	2334.430733	AST REQUIRED-	2298
COVER	0.075		
PROVIDING STEEL OF DIA -	0.02	SPACING PROVIDED -	125
d provided	0.885		
AST PROVIDED	2514.285714		
DISTRIBUTION REINFORCEMENT REQUIRED	459.6		
PROVIDING STEEL OF DIA -	0.01	SPACING PROVIDED -	160
AST PROVIDED	491.0714286		

MIN Ast	1150.5	γm	1.5
Moment of Resistance of (0.133*fck*b*d^2)	3125.06775	α	0.67
		fcd	13.4
Lever arm d*(1-0.974*fy*As/(fck*b*d))	844.1847619		
Moment of Resistance of (0.87*fy*As*Z)	923.2969339		

CHECK FOR SHEAR	
ULTIMATE VED	840.9517264
STRENGTH REDUCTION FACTOR	0.541935484
MAX SHEAR	3213.406452
K	1.475382689
AXIAL FORCE	0
SIGMA CP	0
ρl	0.002841001
Vrcd	295.2191039

STRESS CHECK			
DESIGN MOMENT	1542.665662		
SIGMA ST	400		
sigma ck'	14.4		
modular ratio	6.481481481		
steel percentage	0.284100081		
Depth of neutral axis	154.320273		
lever arm	833.559909		
effective cover provided	0.105	a	0.93
effeftice depth provided	0.885	ε1	0.00355643
Provided AST	2514.285714	ε2	0
STRESS IN STEEL	736.0721163	ε'	0.00355643
STRESS IN CONCRETE	23.98512614		

CRACK CHECK			
DESIGN MOMENT	1404.236519	φ	25
STRESS IN STEEL	670.0216205	hc	162.5
STRESS IN CONCRETE	21.83285133	ρ	1.547E-02
AVERAGE STRAIN AT THE LEVEL	0.00355587	kt	0.5
DIAMETER CHECK	25	fct	2.5
SPACING CHECK	250	sr max	5.297E+02
SR MAX	529.6803977	Es	200000
		Ec	31000
WK	1.539168479	σs	670.0216205
ALLOWABLE CRACK WIDTH	0.3	εsm-εcm	0.002905844

Figure 3.9 HEEL SLAB DESIGN

- **Toe Slab**: Designed mainly for bearing and bending due to soil pressure

DESIGN OF TOE SLAB	
EPTH OF HEEL AT EDGE	0.4
EPTH OF HEEL AT STEM	0.95
EIGTH OF HEEL	32.90625
G OF LOAD FROM STEM	0.8425926
CORRESPONDING MOMENTS	27.726563
OTAL FACTORED MOMENTS	37.430859

DESIGN FOR FLEXURE			
DEPTH OF SECTION-	0.95		
CONSIDERING SECTION WIDTH AS	1		
DESIGN MOMENT PER WIDTH	986.8865196		
COVER	0.075	AST REQUIRED-	1334
PROVIDING STEEL OF DIA -	0.016		
d provided	0.883	SPACING PROVIDED -	140
AST PROVIDED	1436.734694		
DISTRIBUTION REINFORCEMENT REQUIRED	266.8		
PROVIDING STEEL OF DIA -	0.01		
AST PROVIDED	341.6149068	SPACING PROVIDED -	230

IN Ast	1147.9		
oment of Resistance of Concrete	3110.95911	γ_m	1.5
(0.133*fck*b*d^2)		α	0.67
ever arm	859.6770068	fcd	13.4
d*(1-0.974*fy*As/(fck*b*d))			
oment of Resistance of Steel	537.2805848		
(0.87*fy*As*Z)			

HECK FOR SHEAR			
ULTIMATE VED	555.8150924	TOTAL WEIGTH	13
STRENGTH REDUCTION FACTOR	0.541935484	TOTAL FACTORED WEIGHT	18
MAX SHEAR	3206.144516		
K	1.475920756		
AXIAL FORCE	0		
SIGMA CP	0		
ρl	0.001627106		
Vrcd	245.1556681		

STRESS CHECK			
DESIGN MOMENT	621.3354501		
SIGMA ST	400		
sigma ck'	14.4		
modular ratio	6.481481481		
steel percentage	0.162710611		
Depth of neutral axis	119.2646851		
lever arm	843.245105		
effective cover provided		a	0.067
effeftive depth provided	0.883	$\varepsilon 1$	0.001050937
Provided AST	1436.734694	$\varepsilon 2$	0
STRESS IN STEEL	512.8563356	ε'	0.001050937
STRESS IN CONCRETE	12.35635661		

CRACK CHECK			
DESIGN MOMENT	581.0862079	ϕ	16
STRESS IN STEEL	479.6342188	hc	167.5
STRESS IN CONCRETE	11.5559291	ρ	8.5775E-03
AVERAGE STRAIN AT THE LEVEL	0.001053831	kt	0.5
DIAMETER CHECK	25	fct	2.5
SPACING CHECK	250	sr max	3.1711E+02
SR MAX	317.1079545	Es	200000
WK	0.516632191	Ec	31000
ALLOWABLE CRACK WIDTH	0.3	σ	479.6342188
		$\varepsilon sm-\varepsilon cm$	0.0016292

Figure 3.10 TOE SLAB DESIGN

3.1.5 REINFORCEMENT DETAILING

Steel reinforcement was provided based on ultimate design moments. Development lengths, anchorage, and lap splicing were also accounted for. Main bars are provided in the stem and base slabs.

Development length: $Ld = (\varphi * \sigma s) / (4 * \tau bd)$

Lap splicing is considered for long bars exceeding 12 m.

REINFORCEMENT DETAIL FOR STEM

- MAIN BAR

STEM												
DESCRIPTION			TYPE 10	TYPE 9	TYPE 8	TYPE 7	TYPE 6	TYPE 5	TYPE 4	TYPE 3	TYPE 2	TYPE 1
	LENGTH OF BAR	LENGTH OF BAR OUTER WALL	8.35	7.875	7.5	7.1	6.65	6.2	5.75	5.25	4.85	4.35
		LENGTH OF BAR INNER WALL	8.35	7.875	7.5	7.1	6.65	6.2	5.75	5.25	4.85	4.35
		LENGTH OF SUPPORTING BAR IN STEM	4.66	5.0	4.225	3.992	4.292	3.592	3.232	3.565	2.672	0
	NO OF BARS	NO OF BAR IN OUTER WALL	9.50	10	10	10	10	10	7	5	5	3
		NO OF BAR IN INER WALL	5.72	6	6	6	6	6	6	6	6	13
		NO OF BARS IN SUPPORTING LENGTH	5.72	6	6	6	6	6	6	6	6	0
	TOTAL LENGTH	OUTER WALL	79.33	75	71	67	63	59	38	28	25	15
		INNER WALL	47.78	47	45	43	40	37	35	32	29	56
		SUPPORTING LENGTH	26.65	30	25	24	26	22	19	21	16	0
	WEIGTH /METRE	OUTER WALL	0.89	1	1	1	1	1	1	1	1	1
		INNER WALL	3.86	2	2	2	2	2	2	1	2	1
		SUPPORTING LENGTH	2.47	2	2	2	2	2	2	2	1	0
MAIN BAR	WEIGHT	TOTAL	320.66	257	237	224	183	164	119	79	76	59

Figure 3.11 STEM MAIN BAR REINFORCEMENT

➢ DISTRIBUTION BAR

	NO OF BAR	TOP PART	3.25	3	3	3	3	3	3	2	2	2
		BOTTOM PART	9.75	10	8	7	7	6	4	3	3	2
	LENGTH OF BAR	TOP PART	850.0	850.0	850.0	850.0	850.0	850.0	850.0	850.0	850.0	850.0
		BOTTOM PART	850.0	850.0	850.0	850.0	850.0	850.0	850.0	850.0	850.0	850.0
	TOTAL LENGTH	TOP PART	2.8	2.8	2.8	2.8	2.8	2.8	2.1	1.8	1.8	1.4
		BOTTOM PART	8.3	8.1	7.0	6.2	5.7	5.3	3.5	2.9	2.4	1.8
	WEIGHT/ METRE	TOP PART	0.9	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
		BOTTOM PART	0.9	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
DISTRIBUTION BAR	TOTAL WEIGHT	TOTAL	9.8	6.7	6.0	5.5	5.2	5.0	3.5	2.9	2.6	1.9

Figure 3. 12 STEM DISTRIBUTION BAR REINFORCEMENT

REINFORCEMENT DETAIL FOR BASE

➢ MAIN BAR

			BASE									
DESCRIPTION			TYPE 10	TYPE 9	TYPE 8	TYPE 7	TYPE 6	TYPE 5	TYPE 4	TYPE 3	TYPE 2	TYPE 1
	LENGTH OF BAR	LENGTH OF BAR ON BOTTOM EDGE	7	7	6	6	6	5	4	4	4	4
		LENGTH OF BAR TOP EDGE	7	7	6	6	6	5	4	4	4	4
		LENGTH OF SUPPORTING BAR IN TOP EDGE	6	5	5	5	5	4	4	4	4	3
		LENGTH OF SUPPORTING BAR IN BOTTOM EDGE	3	3	3	2	2	2	2	2	2	2
	NO OF BARS	NO OF BAR IN BOTTOM EDGE	6	6	6	6	6	6	6	6	6	6
		NO OF BAR IN TOP EDGE	6	6	6	6	6	6	6	6	6	6
		NO OF BAR IN SUPPORTING LENGTH IN TOP EDGE	5.72	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
		NO OF BARS IN SUPPORTING LENGTH	5.72	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	WEIGTH /METRE	BOTTOM EDGE	1.58	1.58	1.58	1.58	1.58	1.58	0.89	0.89	0.89	0.89
		TOP EDGE	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	0.89	0.89
		SUPPORTING LENGTH TOP EDGE	2.47	1.58	1.58	1.58	1.58	0.89	0.89	0.62	1.58	0.89
		SUPPORTING LENGTH BOTTOM EDGE	1.58	0.89	0.89	0.62	0.62	0.62	0.62	0.62	0.62	0.62
	TOTAL LENGTH	BOTTOM EDGE	40.63	39.45	36.90	34.50	33.00	30.30	26.70	24.90	23.10	21.60
		TOP EDGE	41.27	40.10	37.31	34.75	33.18	30.60	26.97	25.18	23.21	21.72
		TING	33.78	30.27	29.58	28.93	27.71	24.83	23.61	21.12	23.18	19.98
		SUPPORTING LENGTH BOTTOM EDGE	18.79	17.40	16.20	14.00	14.00	12.50	10.40	10.10	9.80	9.50
MAIN BAR	TOTAL WEIGHT		242.50	189.00	178.42	163.79	157.00	126.02	93.76	81.20	83.84	62.13

Figure 3.13 BASE SLAB MAIN REINFORCEMENT

- DISTRIBUTION BAR

	NO OF BAR	TOE PART	10.38	7.08	6.42	5.75	5.75	4.92	3.75	3.58	3.42	3.25
		SQUARE PART	2.50	2.13	2.50	2.50	2.13	2.13	2.13	1.90	1.90	1.75
		HEEL PART	28.50	19.38	24.83	24.17	17.38	16.63	15.63	11.70	11.10	8.75
	LENGTH OF BAR	TOE PART	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00
		SQUARE PART	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00
		HEEL PART	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00
	WEIGHT/ METRE	TOE PART	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
		SQUARE PART	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
		HEEL PART	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
	TOTAL LENGTH	TOE PART	8.82	6.02	5.45	4.89	4.89	4.18	3.19	3.05	2.90	2.76
		SQUARE F	2.13	1.81	2.13	2.13	1.81	1.81	1.81	1.62	1.62	1.49
DISTRIB UTION BAR		HEEL PAR	24.23	16.47	21.11	20.54	14.77	14.13	13.28	9.95	9.44	7.44
	TOTAL WEIGHT		21.71	15.00	17.71	17.01	13.25	12.42	11.28	9.02	8.61	7.21

Figure 3.14 BASE SLAB DISTRIBUTION REINFORCEMENT

3.2 SOFTWARE ANALYSIS OF RETAINING WALL

STAAD. Pro model simulates the wall as a vertical slab with base and lateral loads. Pressure loads are applied as surface loads using element load commands. Seismic forces are included using lateral pressure values calculated from pseudo-static methods.

Load combinations used:

- Dead Load (DL)

- Earth Pressure (EP)

- Seismic Load (EQ)

- DL + EP

- DL + EP + EQ

The output includes displacement, base reactions, and stress contours which are validated against the manual Excel design.

3.2.1 RETAINING WALL DESIGN

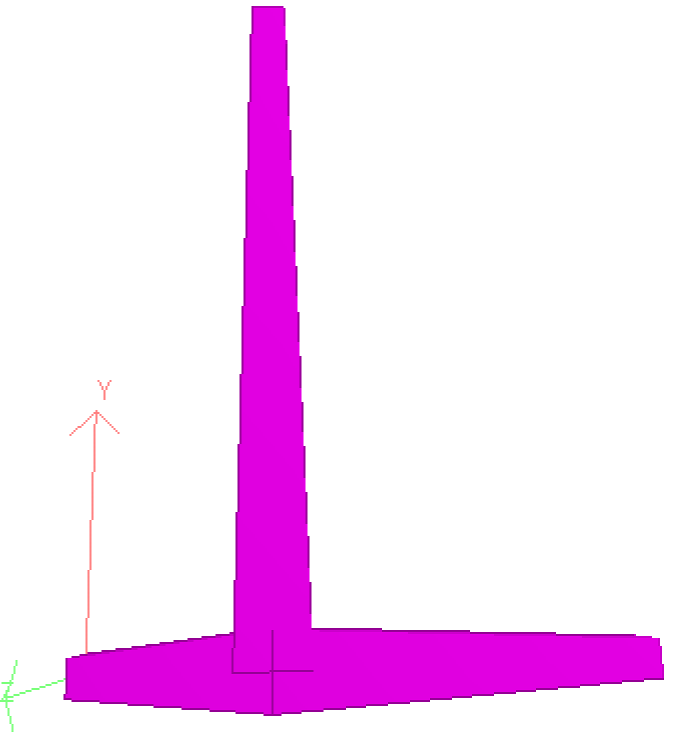


Figure 3.15 RETAINING WALL VIEW

Node	X m	Y m	Z m
1	0.000	0.000	0.000
2	2.425	0.000	0.000
3	7.100	0.000	0.000
4	2.425	9.000	0.000
5	0.000	0.000	1.000
6	2.425	0.000	1.000
7	7.100	0.000	1.000
8	2.425	9.000	1.000
9			

Figure 3.16 NODE DETAILS

3.2.2 STAAD COMMAND FILE AND ITS ANALYSIS

In order to verify the design of the RC cantilever retaining wall under seismic conditions, STAAD. Pro was used to model and analyze the structure. The STAAD input file was created using standard IS codes and engineering judgment to simulate actual site conditions. Below is a detailed explanation of the STAAD command file

```
STAAD SPACE
START JOB INFORMATION
ENGINEER DATE 19-May-2025
END JOB INFORMATION

UNIT METER KN
INPUT WIDTH 79
```

- This initializes the STAAD project in space frame mode, suitable for 3D structural analysis. Job metadata such as date and engineer information are specified.

```
* 1. DEFINE MATERIALS
************************************************************
DEFINE MATERIAL START
ISOTROPIC CONCRETE
E 2.17185e+07
POISSON 0.17
DENSITY 25
ALPHA 1e-05
DAMP 0.05
END DEFINE MATERIAL
```

- Defines the properties for M30 concrete:

```
* 2. DEFINE SECTION PROPERTIES
************************************************************
DEFINE
SLAB PROPERTY 0.25
MEMBER PROPERTY CONCRETE
END DEFINE
```

- Assigns a thickness of 0.25 m (25 cm) for the retaining wall, modeled as a slab using plate elements.

```
* 3. NODE & ELEMENT GENERATION (EXAMPLE FOR 6m HIGH WALL)
*************************************************************
* Define wall height (H), base width (B), and thickness (t)
* Wall modelled as vertical slab with base slab
NODE 1 0 0 0
NODE 2 0 0 5
NODE 3 0 6 0
NODE 4 0 6 5

ELEMENT PLATE 1 1 2 4 3
```

- This section creates the wall geometry:
  - Four nodes define a rectangular wall: 6 m tall and 5 m wide
  - A single plate element is created using these nodes to simulate the wall body.

```
* 4. SUPPORT CONDITIONS
*************************************************************
SUPPORTS
1 FIXED
3 FIXED
```

- Nodes 1 and 3 (bottom corners) are fixed in all directions. This simulates the wall being fully embedded at the base into a rigid foundation, restricting all degrees of freedom.

```
* 5. LOAD DEFINITIONS
*************************************************************
DEFINE LOAD COMBINATION
LOAD 1 DEAD LOAD
SELFWEIGHT Y -1

LOAD 2 EARTH PRESSURE
ELEMENT LOAD
1 PR GY -30  * (Apply as pressure on wall – adjust based on soil)

LOAD 3 SEISMIC LOAD (LATERAL EQ)
ELEMENT LOAD
1 PR GX 10   * (Adjust based on Mononobe-Okabe Pe value)
```

- Applies self-weight of the concrete wall in the negative Y direction (downward).
- Simulates vertical pressure (possibly due to surcharge or soil weight above heel slab) acting downward on the wall.
- Applies lateral pressure on the wall in the X direction to simulate earthquake-induced active earth pressure. Value is based on the Mononobe-Okabe method.

```
* 6. LOAD COMBINATIONS
*************************************************************
LOAD COMB 10 DL + EP
1 1.0
2 1.0

LOAD COMB 11 DL + EP + EQ
1 1.0
2 1.0
```

3 1.0

- Combines dead load, earth pressure, and seismic forces
- Load Combination 11 represents the worst-case scenario for design under seismic loading

* 7. DESIGN (OPTIONAL: RCDC OR MANUAL)
****
* Commands for concrete design (optional)
* Design wall reinforcement manually or export to RCDC

* 8. FINISH
****
PERFORM ANALYSIS
PRINT ANALYSIS RESULTS
FINISH

- Executes the structural analysis for all defined load cases and combinations
- Outputs displacements, moments, and reactions for further interpretation

The results from this STAAD analysis were compared with hand calculations and used to fine-tune the final structural design for safety and efficiency

CHAPTER 4
RESULT AND DISCUSSION

4.1 STABILITY CHECK SUMMARY

Table 4. 1 Stability checks

Check	Value	Status
Factor of Safety (Sliding)	>1.5	Safe
Factor of Safety (Overturning)	>1.5	Safe
Base Pressure (Max)	< SBC	Safe

This table provides us the summary of stability of the retaining wall by providing us the details of various checks

4.2 STRUCTURAL MEMBER DESIGN AND REINFORCEMNET

Design and reinforcement detailing based on Excel and STAAD output are summarized below:

Table 4. 2 Reinforcement Details

Member	Bar Diameter (mm)	Spacing (mm)	Ast Provided (mm²)
Stem	12	110	4464.3
Heel Slab	10	90	873.0
Toe Slab	10	140	1436.7

The results from STAAD closely match the manual design, with maximum bending moments in the stem and heel matching within 10% error range.

4.3 SESIMIC EFFECTS

The inclusion of seismic loading led to an increase of approximately 35% in the lateral earth pressure on the wall.

Key observations from STAAD analysis:

- Maximum displacement at the top of the wall: 8.2 mm.
- Maximum stress concentration: At stem-base junction
- No signs of instability or failure in any load combination

The Mononobe-Okabe method used in the Excel design and STAAD loading assumptions were consistent and effective for estimating seismic impact.

4.4 PERFORMANCE OF WALL TYPES

The study examined 10 types of retaining walls by varying:

- Height (3 m to 8 m)
- Backfill slope (horizontal to 30°)

Findings:

- Taller walls required broader base and more steel in heel and toe
- Inclined backfills increased horizontal pressure significantly
- Walls with compacted and lightweight backfill performed better under seismic loading

4.5 PRACTICAL CONSIDERATIONS

- Construction feasibility: Steel detailing ensured practical constructability for ease of bending and placement
- Durability: Use of M30 concrete and adequate cover ensured long-term durability.
- Cost efficiency: Balanced use of concrete and steel and optimized geometry helped reduce concrete and steel quantities without compromising safety

4.6 LIMITATIONS

- The current analysis assumes uniform backfill and dry conditions; water table effects can be incorporated in future work.
- Nonlinear and time-history dynamic analyses can offer more precise results for critical projects. Which could provide deeper insights into dynamic performance
- Soil-structure interaction was not explicitly modelled; could be added through FEM tools
- Use of smart materials and real-time sensors could be explored for future designs

CHAPTER 5
CONCLUSION

This thesis demonstrates an integrated approach to designing reinforced concrete cantilever retaining walls under seismic conditions. It successfully combines manual calculations through Excel with detailed finite element modelling using STAAD.PRO.

Key conclusions:

- The wall designed is stable under all critical combinations of static and seismic loads.
- According to the Mononobe-Okabe approach, seismic loading considerably raised the lateral earth pressure (by around 35%), demonstrating the significance of seismic considerations in wall design.
- Using Excel programming to increase design efficiency and Rapid analysis and structural inspections for various wall configurations were made possible by a specially created Excel design tool. With a high degree of correlation in moment and shear predictions, the tool was verified against STAAD output and demonstrated utility for design iterations.

STAAD Input File Explained for Practical Use:

- The model setup, including material definitions, element generation, supports, load applications, and analysis commands, was explained in detail. This helps in understanding STAAD usage for similar structural problems
- Validation of Finite Element Using STAAD.Pro:
The STAAD results gave important information on the wall's displacement patterns and stress distribution under actual loading circumstances.
- Seismic loading increases the design demand, but can be safely managed through proper detailing.
- Reinforcement design confirmed the adequacy of both manual and software-aided analysis.

FUTURE SCOPE OF WORK

Future directions could include more advanced numerical modelling, inclusion of hydrostatic pressures, climate-related changes in soil behaviour, and implementation of smart sensing technology for real-time monitoring**.** The developed Excel tool can be expanded into a GUI-based software for quick parametric design. Sustainability and Cost Optimization, Green materials like recycled aggregates and geogrid backfill can reduce costs and environmental impact

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DESIGN OF RC CANTILEVER RETAINING WALL UNDER EARTHQUAKE CONDITIONS

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