مركز التنمية العالمي
International Development Center

Professional Diploma
In
Structural Analysis and Design
Using American and British Codes
(Civil Engineering)

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Part I. General Scientific Introduction :

The contents of this section will be presented in the form of a Structure training Program. This course will provide an integrated theoretical, practical and technical approach that includes a summary of past experiences in this field and unique additions. So that the recipient of the course has a complete and comprehensive knowledge of all aspects of analysis and structural design.

1. **General Aims :**
   a) Provide a summary of the structural analysis and design methodology so that the course instructor is able to carry out structural design work with all skill.
   b) Provide a reliable construction engineer for the community with full qualification and creative work.
   c) Promote the analytical thinking of the problems facing the student and how to devise solutions and choose the best solution.
   d) Provide an effective training program for the student to apply all the theoretical and technical knowledge learned from the Program.
2. **Educational Methods:**
   a) Theoretical lectures by advanced educational methods (intelligent screens – projector - …).
   b) Technical training on the most important applications of analysis and structural design.
   c) A set of periodic tests for each Chapter will be taught.
3. **Exposed with the Program**
   a) Consultants, engineers and contractors.
   b) University students interested in construction.
4. **Program Characteristics**
   - A certified diploma from the American University of London documented by the Department of Higher Education in France.
   - An integrated learning center, an ideal learning environment and teachers with a high degree of proficiency and experience.
   - A certificate approved by the International Development center.
   - Practical Application opening the chance in participation analysis and design
   - Practical training by giving students the opportunity to design a set of construction projects proposed in cooperation with a group of construction and consulting companies.

Part II. The Technical Academic Program

Chapter one: Study of concepts and theories in Structural Analysis (10 Hours)

1. General Concepts

Definition of the Structure, load distributions, forces acting on the structure, types of Hinges, static equations, definitions of concepts (concrete pressure / types of reinforcing steel / design loads / effective span and bending moment and shear force diagram

2. Analysis of Frames :

a) Find the support reactions. (By using the equations of equilibrium and the equations of condition if any).

b) Find the member end force.

c) Plot the axial force, shear force and bending moment diagrams on an outline of the frame.

3. Analysis of Trusses :

a) Reasons **of using trusses**

Long span, light weight, control of deflection, and great load ability

b) Analysis **using balance of joints method**

(This method is used if desired forces are found in all truss members)

1. It is preferable to find reactions on the joints.
2. Members with zero moments are considered as non-existent.
3. Start by finding the nodes that have two members using the equilibrium equations (the sum of the vertical forces equal zero ,also horizontal forces)
4. It is preferable to start with a balancing equation, one of which can be found directly.
5. Repeat steps 2 and 3, but this time for joints that has more than two members and on condition that the number of unknowns is higher than two.
6. Continue to apply step 4 until forces are found in all members

It is very important to determine the type of force in each member. Is it a tension or a compression?

It is also very important to write units.

c) Analysis using section method

(We use this method if it is required to find forces in some members only, especially if it is near the middle of the truss and not its sides.)

1. It is preferable to find reactions on the joints.
2. Find a section that passes by the forces that need to be calculated and preferably more than three members.
3. separate one side of the section and apply equilibrium equations
4. It is preferable to apply the equation $\sum M = 0$ more than once at the convergence of two unknowns, to find the third unknown from one equation.

5. In the case of parallel two members can be used in the vertical direction on them to find the third unknown.
6. The sectioning can be repeated a to find forces in the members that are not covered by the section.
7. The use of the joint balancing method can be combined with section method to find forces in members not covered by the section

4. Analysis of Arches

Circular three-hinged arch:

a) The vertical and horizontal components *V* and *H* of the stress resultants *N* and *Q* at an arbitrary section parameterized by the angle.
b) Determine the bending moment *M*

5. Deflection

Is the effect of external loads on the structure in the form of displacement or rotation at an angle, and the causes of deflection due to the early decomposition of wooden nodes and design errors like lack of reinforcing steel or concrete section?

Deflection depends on: load and it place, length of beam, moment area, and elasticity

Types of Deflection:

1. short term deflection : The immediate effect of loads on the structure occurs from the moment the wrenches are removed and loading of structure begins
2. Long term deflection : Occurs after the long time as a result of occurrence of creep and shrinkage .

Methods of calculating Deflection :

a) Energy Method

Known as Castigliano's Theorem

when the body deflects flexibly by any set of loads, the deviation at any point and in any direction is equal to a partial derivative of the stress energy (calculated with all the moving loads) with respect to the load at the point:

$$\Delta = \partial U/\partial Q$$

b) double integration Method

The dual integration method is a powerful tool in solving the deviation and slope of the beam at any time because we will be able to obtain a flexible curve equation. The basic advantage of the dual integration method is that it produces a deviation equation everywhere along the beam:

$$EI.y'' = M$$

c) Moment area :

In this method, the area of bending moment diagram is used to calculate the inclination and / or deviations at certain points along the axis of the beam or frame. This is the fastest way to calculate the deviation at a given location if bending is a simple curve bending scheme.

It is the method by which the integration of the moment of bending indirectly, using the geometric characteristics of the area under the bending moment diagram.

$$\theta_{B/A} = \theta_B - \theta_A$$

$$\theta_{\frac{B}{A}} = Area\ of\ \frac{M}{EI}\ diagram$$

Chapter Two: Advanced Theories in structural Analysis I (10 Hours)

1.Slope Deflection Method :

In this Method the relationship between the Moments at the ends of the Members is established against the displacement and rotation. The basic assumption used in this method is that the member can bend but the shear and the axial deformation are ignored. The basic idea of this method is to write the equilibrium equations for each node in terms of deviations and rotation, Dissolution of public displacement, Using moment and displacement relationships, and then finding the moment.

Analysis of Beams – Slope-Deflection Method :

1. Scan the beam and identify the number of (a) segments and (b) kinematic unknowns
2. For each segment, generate the two governing equations. Check the end conditions to see whether one of the end rotations is zero or not (it is not possible for both the end rotations and other deflection components to be zero). If there are no element loads, the FEM term is zero. If there are one or more element loads, use the ppropriate formula to compute the FEM for each element load and then sum all the FEMs.
3. For each kinematic unknown, generate an equilibrium condition using the free-body diagram.
4. Solve for all unknowns by combining all the equations from steps 2 and 3.
5. Compute the support reactions with appropriate FBDs.

Analysis of Frames without Sides way – Slope-Deflection Method

The analysis of frames via the slope-deflection method can also be carried out systematically by applying the two governing equations of beams.

A sides way will not occur if (a) The frame geometry and loading are symmetric, and (b) sides way is prevented due to support.

2.Moments Distribution Theory :

In Moments distribution method, each detailed structure is analyzed to obtain constant endurance. Then the static end distributions are distributed to adjacent elements until equilibrium occurs. . The method is solved mathematical by means of a set of interrelated equations and a repeat function until solving these equations.

In order to apply Moments distribution method to analysis a structure , these conditions must be considered (constant endurance moments, bending Stiffness (EI / L), distribution factors).

3.Casigiliano's second theory I

The partial derivative of complementary energy U * in relation to the load leads to the displacement component of the load point in the direction of this load**:**

$$\frac{\partial U^*}{\partial P_i} = D_i$$

P_i Can be force F or moment M

$$\frac{\partial U^*}{\partial F_i} = \Delta_i \quad , \quad \frac{\partial U^*}{\partial M_i} = \theta_i$$

4. Three Moments Theory I

Is a relationship between the bending moments in three successive supports of horizontal beam :

$$\frac{M_1 L_1}{E_1 I_1} + 2M_2\left(\frac{L_1}{E_1 I_1} + \frac{L_2}{E_2 I_2}\right) + \frac{M_3 L_2}{E_2 I_2} = 6\left(\frac{\Delta A - \Delta B}{L_1} + \frac{\Delta C - \Delta B}{L_2}\right) - 6\left(\frac{A_1 X_1}{E_1 I_1 L_1} + \frac{A_2 X_2}{E_2 I_2 X_2}\right)$$

5. Deflection Theories in Trusses :

Steps of solving deflection problems in trusses :

a) Axial deformation because of the direct loading $\boldsymbol{\delta = \frac{PL}{AE}}$

b) Superposition : the total deflection equals the sun of the deformation for any member alone $\Delta_x = \sum_{i=1}^{N} \Delta_x$, where N represents number of members in truss

c) Reciprocal Deflections $\frac{\Delta_x}{\delta_i} = \frac{P_i}{U_x}$

Substituting equations (a) and (c) in (b) , the final equation will be :

$$\Delta_x = \sum \left(\frac{\mathbf{P_i L_i}}{\mathbf{A_i E}}\ \mathbf{P_i}\right)$$

Chapter Three : Advanced Theories in structural Analysis II (10 Hours)

Matrices methods in structural Analysis:

1. **Flexibility Matrix Method:**
   a) **The theory of elasticity for statically determined structures:**
   It can be applied in beams, structures and trusses.
   Steps of solution are:
   - Calculation of degree of redundant
   - Calculate FEM Matrix
   - External forces matrix and unknown displacement matrix
   - Forces transformation matrix
   - Members flexible matrix
   - structure flexible matrix
   - displacement matrix Δ = [F].[P]
   - check from values by applying in equilibrium equations

   b) **The theory of elasticity for statically undetermined structures :**
   - Calculation of degree of redundant
   - Calculate FEM Matrix
   - External forces matrix and unknown displacement matrix
   - Forces transformation matrix
   - Members flexible matrix
   - structure flexible matrix
   - displacement matrix Δ = [F].[P]
   - P= (b'.P + F.E.M)
   - check from values by applying in equilibrium equations and the equation $b_x^T \cdot f \cdot b' = 0$

2. **Stiffness Method Matrix** :
   The most common used methods are known as displacement or equilibrium method. it has three methods:
   - the simple stiffness matrix,
   - the modified stiffness matrix,
   - the direct stiffness matrix

   a) **the simple stiffness matrix:**
   Steps of solving:
   - Calculate FEM Matrix
   - External forces matrix P
   - Displacement shifting matrix

- Structure stiffness matrix K=$a^T.R.a$
- Displacement matrix Δ=$k^{-1}.P$
- Calculation the internal forces P= ΔRa +FEM
- Check P = $a^{-1}p$

b) The modified stiffness matrix

Steps of solving:

- Calculate FEM Matrix.
- External forces matrix P.
- Displacement shifting matrix.
- Structure stiffness matrix K=$a^T.R.a$
- Displacement matrix Δ=$k^{-1}.P$
- Calculation the internal forces P= ΔRa +FEM
- Check $a^T p$=0

c) the direct stiffness matrix

Steps of solving:

- Calculate FEM Matrix.
- External forces matrix P.
- Displacement shifting matrix.
- Structure stiffness matrix K=$\sum K^n$, $K^n = a^{T^n}.R.a^n$
- Displacement matrix Δ=$k^{-1}.P$
- Calculation the internal forces P= ΔRa +FEM
- Check $a^T p$=0

3. The Total Stiffness Method

This method is distinct from the two previous methods, because it does not neglects axial forces and shear forces in the case of beams and frames. Therefore the analysis is more accurate and comprehensive.

Theory Assumptions:

a) Deflections were caused by shear, axial loads and moments all All are taken into account.
b) Neglecting deformations caused by Torsion.

Chapter Four : Structural Design Using British Code (30 Hours):

1. Singly reinforcement rectangular section :

a) Determine the effective span, L, a1 & a2.
b) Determine the design load and forces, M & V.
c) Determine the effective dimensions, d, beff, bw, bv.
d) Design the bars for mid-span moment.
e) Design for the shear at supports.
f) Check deflection by span-to-depth ratio.

2. Design of one way slab:

a) Selection of preliminary depth of slab.
b) Design loads, bending moments and shear forces.
c) Determination/checking of the effective and total depths of slabs.
d) Depth of the slab for shear force.
e) Determination of areas of steel.
f) Selection of diameters and spacing of reinforcing bars.

3. Design of continuous beams:

a) Determining design loads.
b) Determining design forces by force coefficients.
c) Determining reinforcement for bending and shear.
d) Checking deflection by span-to-depth ratio .

4. Design of Stairs:

a) Determine the design life, Exposure class and fire resistance.
b) Determine the material strength.
c) Select the waist, h and average thickness, of staircase.
d) Calculate min. cover of durability, fire and bond requirements.
e) Estimate actions on staircase.
f) Analyze structure to obtain maximum bending moments and shear forces.
g) Design flexural reinforcement.
h) Check shear.
i) Check deflection.
j) Check cracking.

5. Design of Flat Slab :

a) Find moment connection edge and redistribution moments if necessary.
b) Draw bending moment diagrams.
c) Check limitations of negative design moments.
d) Carry out division of panel.
e) Divide moment between column strips and middle strips.
f) Determine cover of reinforcement .
g) Carry out design for flexure.
h) Check punching shear stress at the column head.
i) Shear stress for the critical section .
j) Check deflection .
k) Curtailment and Spacing of bars .
l) Calculate minimum reinforcement .
m) Check thermal cracking .

6. Design of Column subjected to axial force only

a) Analysis.
b) Check of slenderness of column.
c) Determination of cover.
d) Design of short column.
e) Check shear stress.
f) Min and max reinforcement.
g) Containment of reinforcement.
h) Check crack width.

7. Design of Column subjected to an axial load with biaxial bending moments

a) Verification of the eccentricities.
b) Assuming a trial section including the reinforcement.
c) Determination of M_{ux1} and M_{uy1}
d) Determination of P_{uz} and $n\alpha$
e) Checking the adequacy of the section .
f) Design of transverse reinforcement.

8. Design of Isolated Footings :

a) Determining size of footing:
b) Two way shear (Assume a uniform overall thickness of footing, D).
c) Design for flexure (The critical section for flexure occurs at the face of the column).
d) Check for One-Way Shear
(The critical section for one way shear occurs at a distance of 'd' from the face of the column).
e) Check for development length Sufficient development length should be available for the reinforcement from the critical section.

9. Design of combined Footings :

a) Size of the footing.
b) Thickness of footing slab based on one-way shear.
c) Checking for two-way shear.
d) Gross bearing capacity.
e) Bending moments (longitudinal direction).
f) Design of column strip as transverse beam.
g) Transfer of forces at the base of the columns.

Chapter Five: Structural Design Using American Code (30 Hours)

1. design of Flat slab

a) Calculate the thickness of the slab.
b) Selection the loads .
c) determine the shear forces .
d) determine concrete resistance for shear force .
e) calculate bending moments:
- Internal moments (negative 65% from all B.M // positive 35% from total value of BM)
- External moments (negative 26% from all B.M // positive 70% from total value of BM)

2. Design of the hollow slab

a) Determination of the dimensions and thickness of the slab.
b) Load calculation.
c) Reinforcing the slab by arming heat and shrinkage.
d) Rib design:
- Find the load of the slab.
- Thickness resistant to deflection .
- bending moments and shear forces in ribs.

3. Design of columns

a) Columns subjected to axial forces only :

$$P_n = A.g\left(0.85\, f'_c\,(1-P) + \rho f_y\right)$$

The American specification defines design resistance as follows:

For trusted columns $P_{n\,max} = 0.8\, P_n$

For spiral columns $P_{n\,max} = 0.85\, P_n$

The following equations are used when the bending moments are small :

For trusted columns $\frac{e}{h} \le 0.1$

For spiral columns $\frac{e}{h} \le 0.05$

b) Columns subjected to axial force and bending moments

a. From analysis calculate values of Pu ,Mu.
b. Calculate the value of eccentricity e.
c. Assume any dimensions of the column in which we calculate (b, h) and.γ .
d. Calculate K or α.
e. Calculate k.$\frac{e}{h}$ Or α .$\frac{e}{h}$.
f. From graphs find ρ, g.
g. Calculate As.
h. Make sure that $P_{min} \le P \le P_{max}$.
i. If we find P inappropriate we choose another clip.

c) Design also with pressure and tensile control equations .

4. **Design of isolated footings**
   a. Determination of base area according to operating loads "Pw", and soil tolerance "Q net".
   b. Determination of base thickness according to maximum loads:
      - Thickness must meet three requirements.
      - (Punching Shear / shear in one direction / bending moments).
   c. Reinforcement Ru_{rev}.
   d. Check concrete resistance for loading Nu.

5. **Design of combined Footings**
   a. Determination of operating loads and net soil pressure.
   b. Calculate the base area.
   c. Calculate the appropriate dimensions for the base.
   d. Be sure to the punching shear.
   e. Draw the shear force and bending curves in the longitudinal direction.
   f. Ensure thickness to resist shear strength and bending force.
   g. Longitudinal reinforcement calculation.
   h. Calculate the bending curve in the cross direction and then calculate the arming in the cross direction.
   i. Check concrete resistance for loading.

6. **Design of pile foundation**
   a. Determination of operating loads.
   b. Calculate number of piles.
   c. Calculate the weight of the base.
   d. Determination the loads at any pile.
   e. Calculate bending moments and reinforcement .
      - Bending moment at longitudinal direction.
      - Bending moment at shorter direction.
      - Reinforcement calculation at both directions .
   f. Check punching shear around piles.
      - Calculate ΦVc.
      - Check the shear around columns.
      - Check the shear from beam at shorter direction.

7. Design of Raft Foundation

a. Estimate the resultant of loads R.
b. Choosing the dimensions of area .
c. Determine the location of R, then select the displacement e_x / e_y.
d. Calculate the area , centroid , and Ix,Iy.
e. Calculate the bending moments of columns Mx , My.
f. Calculate the potential distribution on soil under the raft .
g. Classified the raft at both directions at the center of columns.
h. Design any section with the maximum stress subjected.

Chapter six : important software applications in structural analysis and design (30 Hours):

Structural analysis and design processes will be taught to the various construction members by the most important applications in the Sudan, which are more desirable for engineers in the structural field:

1. ETABS: Produced by CSI and used in the study and analysis of high facilities and study the impact of the main loads and the horizontal on the building (wind and earthquakes).
2. SAFE: produced by CSI and is specialized in the design of slabs, Raft and foundations of all kinds because of the possibility correspond to the surface and flat elements such as slabs.
3. SAP: produced by CSI, characterized by the easy and accuracy of the design and is distinguished by the design and analysis of reservoirs, silos and domes as well as it is accurate in mechanical loads.

Part III. : Distribution of the hours of the diploma :

	Theme		No. days	No. Hours
1	Structural Analysis	S.A I	2	10
		S.A II	2	10
		S.A III	2	10
2	Structural Design	British Code	6	30
		American Code	6	30
3	software applications	ETABS	2	10
		SAFE	2	10
		SAP	2	10
4	Practical Applying		2	10
5	Diploma Certificates from the University for attendance and examination details		26	130

Part IV. Academic and Technical References :

1. Structural Analysis , Eighth Edition, R.C. Hibbeler (Author).
2. Reinforced Concrete Design Theory and Example ,Thomas J. MacGinley.
3. Matrix Structural Analysis, Second Edition, William McGuire(Author) , Richrad H.Gallagher (Author), Ronald D.Ziemian (Author).
4. Reinforced Concrete Analysis and Design S.S Ray (Author).
5. https://www.csiamerica.com/products.

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Course Routes Offered

Qualification	Route
DBA	BY DIRECTED COURSEWORK STUDY / RESEARCH & DISSERTATION
PhD	BY RESEARCH & DISSERTATION
BBA	BY DIRECTED COURSEWORK STUDY

Course Modules

Module Code	Module Title
SAD11	Analysis of Frames
SAD12	Analysis of Trusses
SAD13	Analysis of Arches
SAD14	Methods of calculating Deflection
SAD21	Slope Deflection Method
SAD22	Moment Distribution Theory
SAD3	Matrices Methods
SAD41	Design of Concrete Structures(British Code)
SAD42	Design of Concrete Structures(American code)