Design of Offshore Structure

By

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Chapter 5： structural analysis (Qusi-static and Dynamic analysis)


Weight +
Dynamic forces

OBJECTIVE

- To present the main analysis procedures for offshore structures. (Qusi-static and Dynamic analysis

outline

- Analytical models used in offshore engineering
- Acceptance criteria for the verification of offshore structures
- Simple rules for preliminary member sizing
- procedures for static in-place
- dynamic analysis

ANALYTICAL MODEL

- Stick models (beam elements assembled in frames) are used extensively for tubular structures (jackets, bridges, flare booms) and lattice trusses (modules, decks).

✓ Joints

✓ Members

- Plate Models (Integrated decks and hulls of floating platforms)

ACCEPTANCE CRITERIA

- Code Checks
- a strength check, where the characteristic resistance is related to the yield strength of the element,
- a stability check for elements in compression where the characteristic resistance relates to the buckling limit of the element.

Allowable Stress Method

- This method is presently specified by American codes (API, AISC).

Limit State Method

- Ultimate Limit State (ULS): corresponds to an ultimate event considering the structural resistance with appropriate reserve.
- Fatigue Limit State (FLS): relates to the possibility of failure under cyclic loading.
- Progressive Collapse Limit State (PLS): reflects the ability of the structure to resist collapse under accidental or abnormal conditions.
- Service Limit State (SLS): corresponds to criteria for normal use or durability (often specified by the plant operator).

- Load factors
- Material factors
- Classification of Design Conditions

PRELIMINARY MEMBER SIZING

Jacket Pile Sizes

- calculate the vertical resultant (dead weight, live loads, buoyancy), the overall shear and the overturning moment (environmental forces) at the mudline.
- assuming that the jacket behaves as a rigid body, derive the maximum axial and shear force at the top of the pile.

- select a pile diameter in accordance with the expected leg diameter and the capacity of pile driving equipment.
- derive the penetration from the shaft friction and tip bearing diagrams.
- assuming an equivalent soil subgrade modulus and full fixity at the base of the jacket, calculate the maximum moment in the pile and derive its wall thickness.

Deck Leg Sizes

- adapt the diameter of the leg to that of the pile.
- determine the effective length from the degree of fixity of the leg into the deck (depending upon the height of the cellar deck).
- calculate the moment caused by wind loads on topsides and derive the appropriate thickness.

Jacket Bracings

- select the diameter
- calculate the axial force in the brace
- derive the thickness

Deck Framing

- select a spacing between stiffeners
- derive the plate thickness.
- determine by straight beam formulae the sizes of the main girders under "blanket" live loads and/or the respective weight of the heaviest equipments.

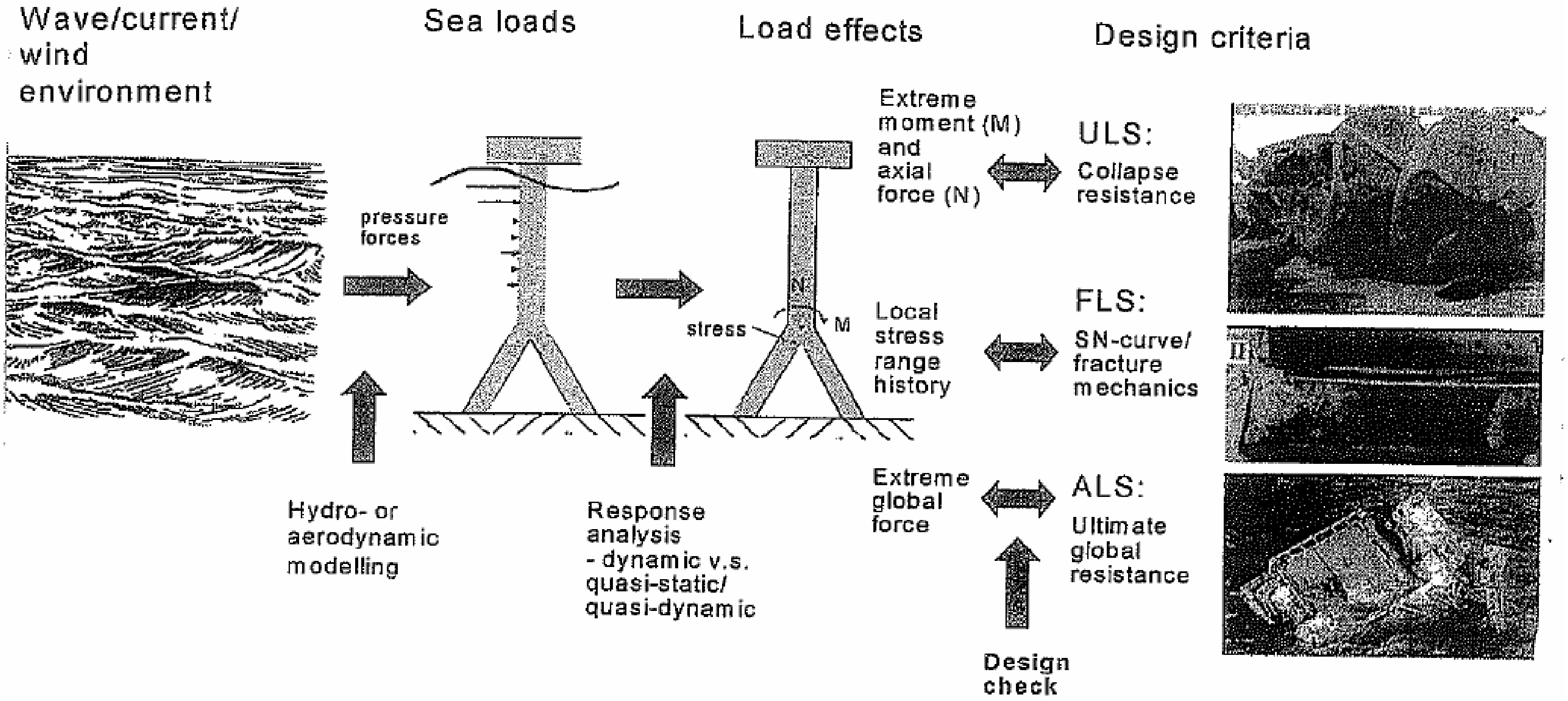
STATIC IN-PLACE ANALYSIS

Structural Model

- Main Model
- Appurtenances
- Foundation Model

Loadings

- Gravity Loads
  - ✓ Dead weight of structure and equipments
  - ✓ Live loads (equipments, fluids, personnel)
- Environmental Loads
- Loading Combinations



Wave/current/ wind environment

Sea loads

Load effects

Design criteria

pressure forces

stress

N

M

Hydro- or aerodynamic modelling

Response analysis
- dynamic v.s. quasi-static/ quasi-dynamic

Extreme moment (M) and axial force (N)

ULS:
Collapse resistance

Local stress range history

FLS:
SN-curve/ fracture mechanics

Extreme global force

ALS:
Ultimate global resistance

Design check

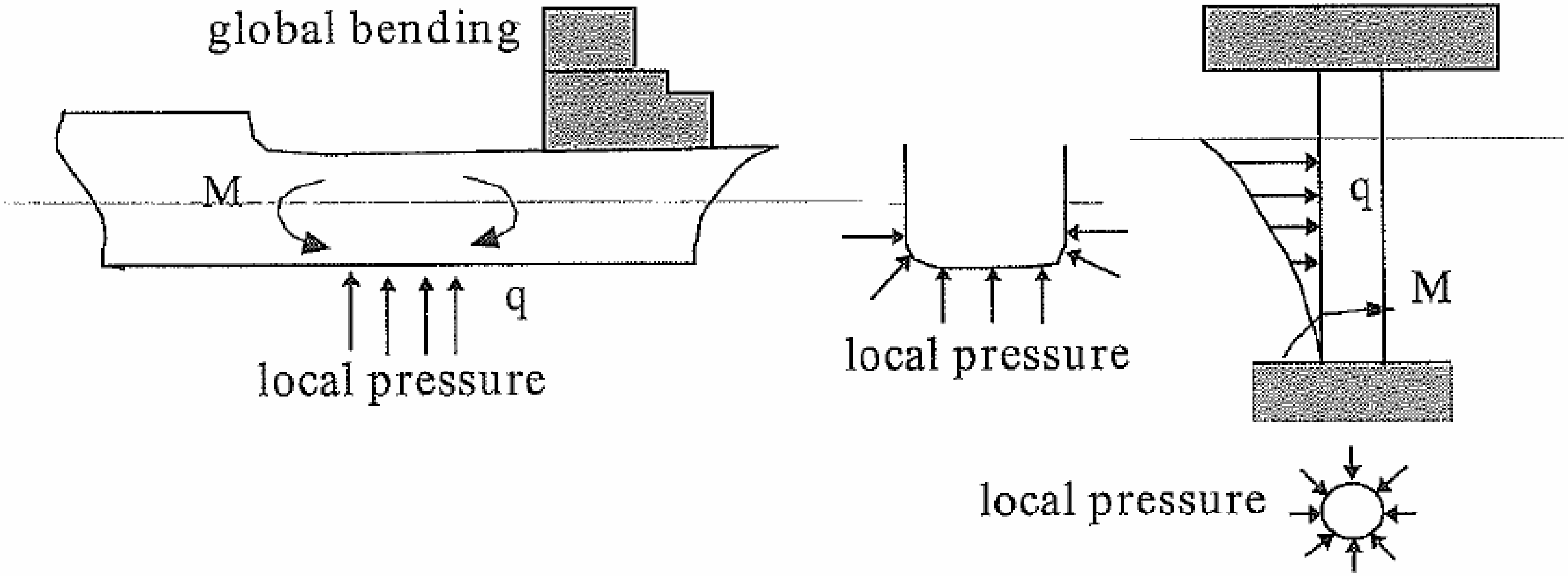
GLOBAL LOAD EFFECT DUE TO FUNCTIONAL AND ENVIRONMENTAL LOADS

(see chapter 4 of lecture notes)

Purpose:

- Determine forces / displacements for design check (ULS, FLS, SLS)
  For ULS: $\gamma_s \cdot S(Q_c)$
- Implication with respect to structural design

- **Spatial effect**

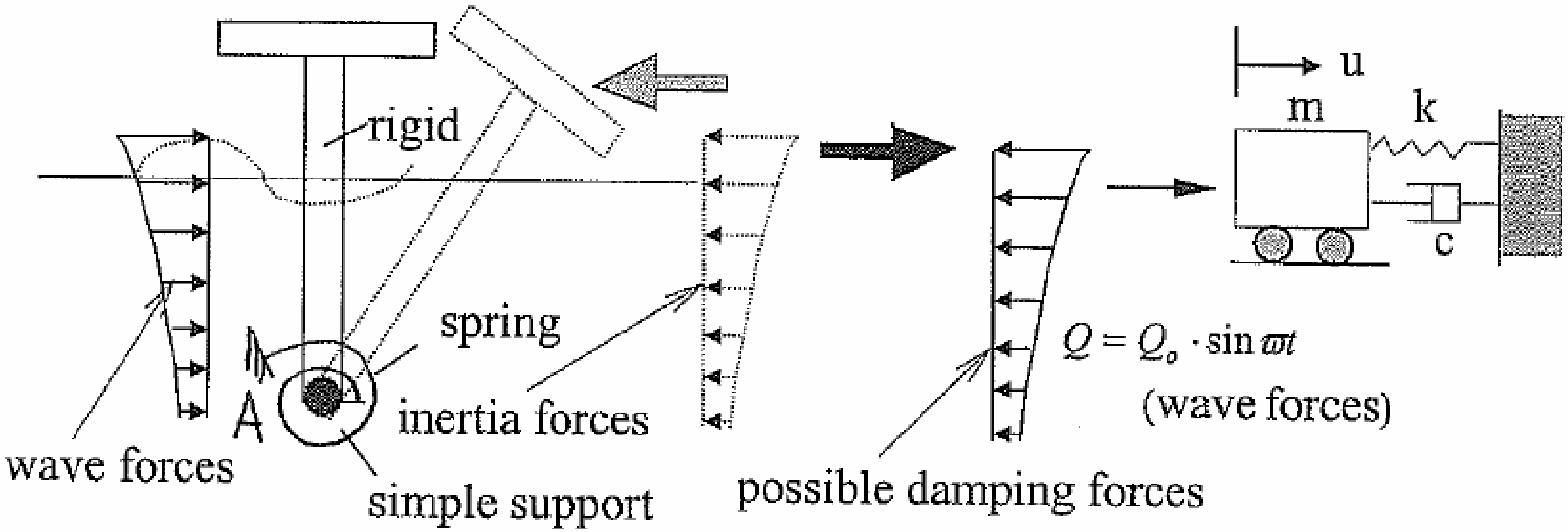


- **Temporal effect**

Time varying loads:
- Static vs. dynamic load effects

includes: inertia and damping forces caused by the motion

Dynamic analysis of a single Degree of Freedom system



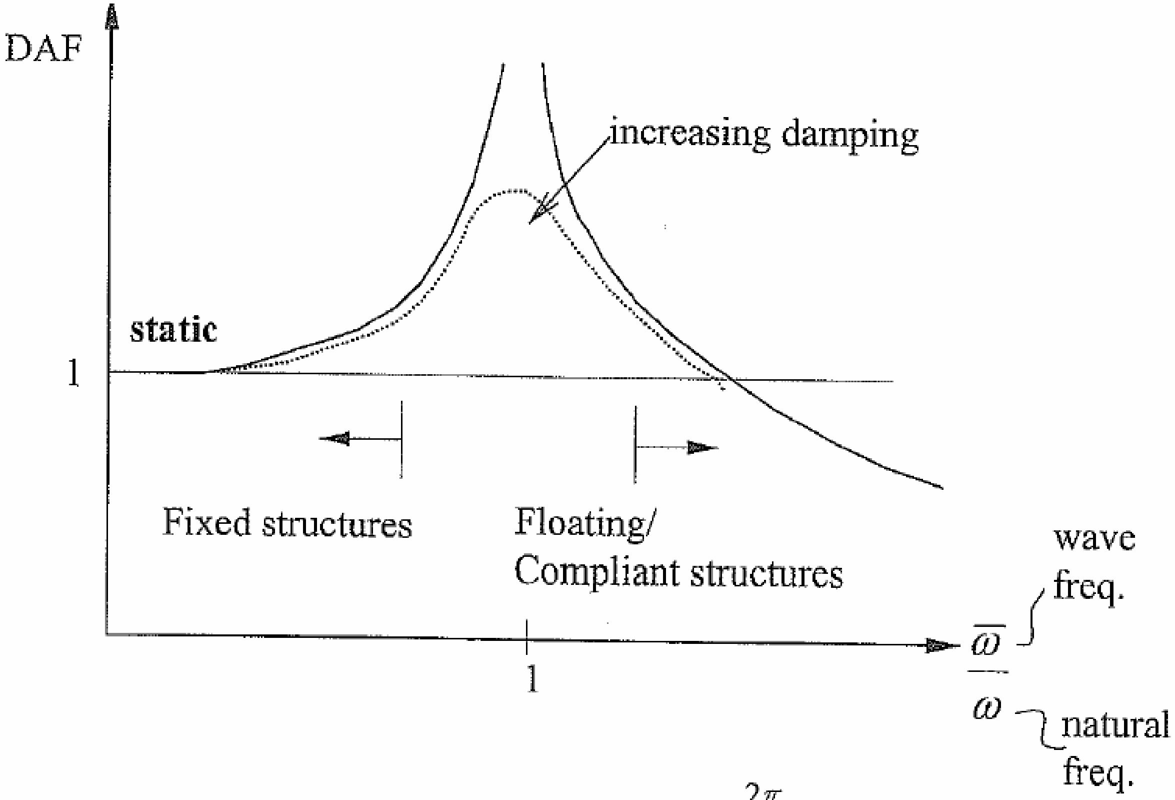
Dynamic equilibrium by

$$\left.\begin{array}{l} -\ \text{inertia}\\ -\ \text{viscous damping}\\ -\ \text{elastic restoring}\end{array}\right\}\ \text{forces}$$

$$m\cdot\ddot{u}+c\cdot\dot{u}+k\cdot u=Q_o\cdot\sin\bar{\omega}t$$

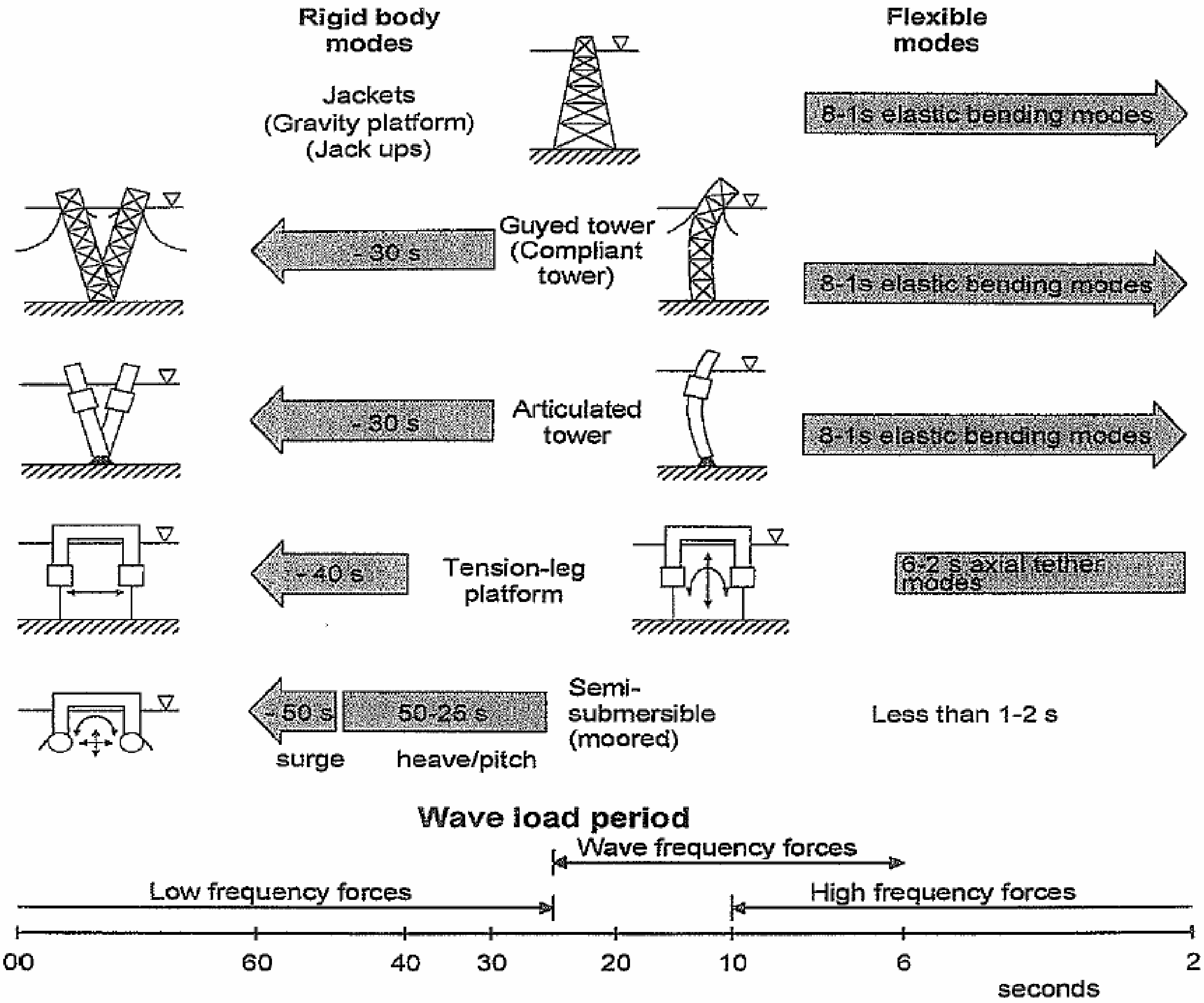
$$u=u_o\cdot\sin(\bar{\omega}t-\varepsilon)=\frac{Q_o}{k}\cdot DAF\sin(\bar{\omega}t-\varepsilon)$$

ε - phase angle; $\frac{Q_o}{k}$ - static solution; DAF - dyn. magnification factor

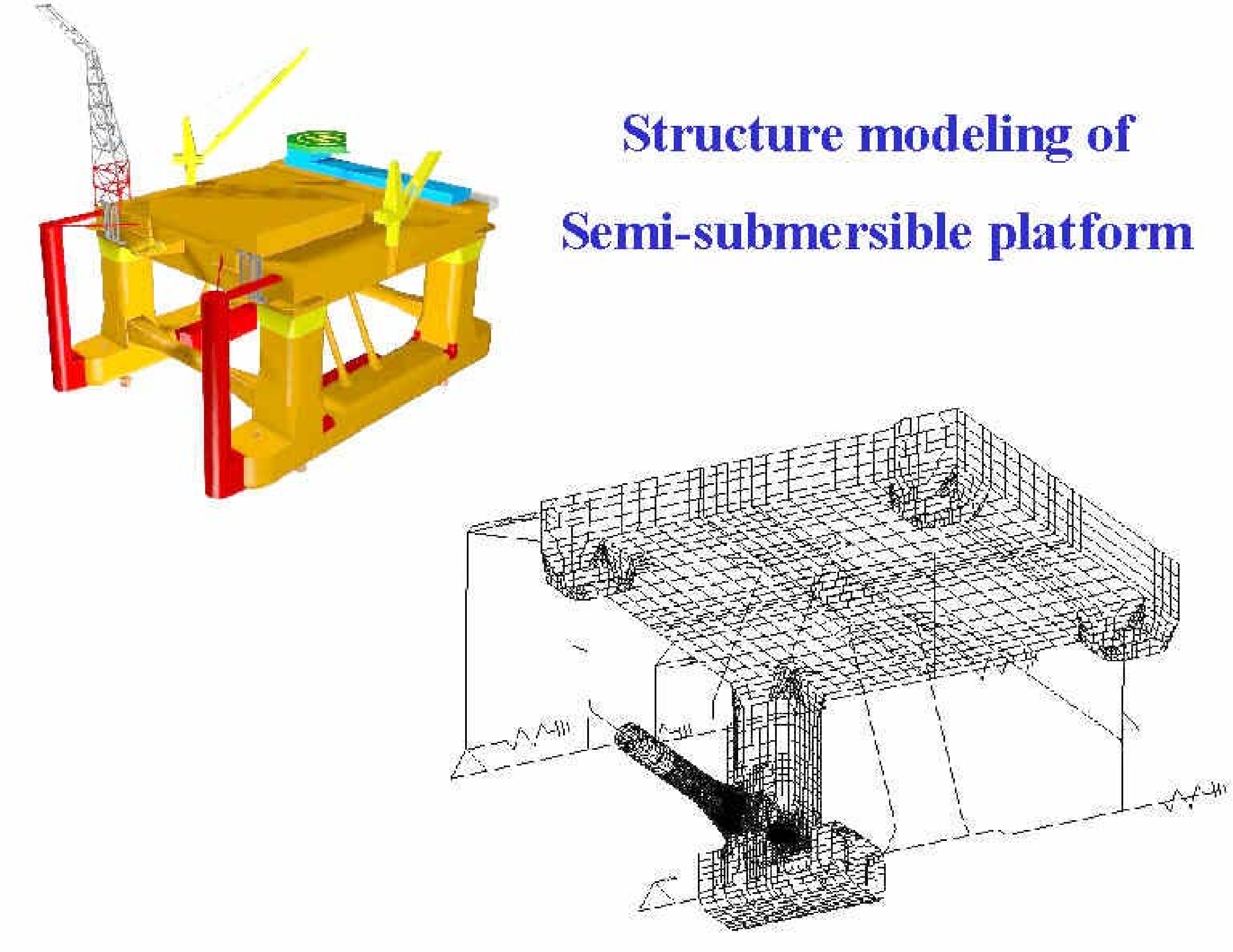


$T=\frac{2\pi}{}$

Natural periods

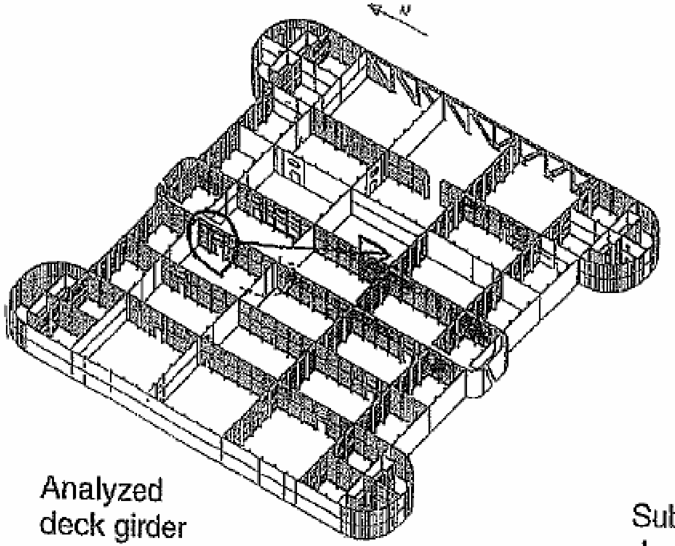


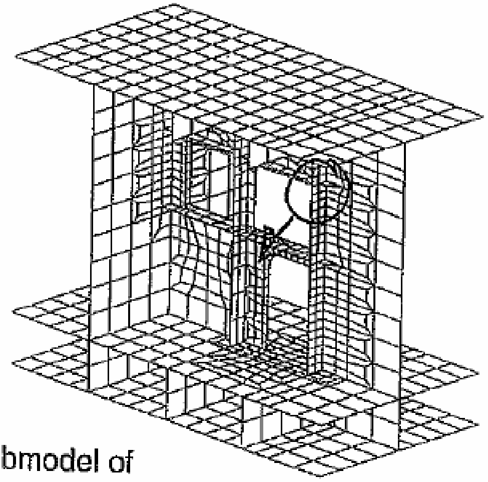
Examples applications of FEM

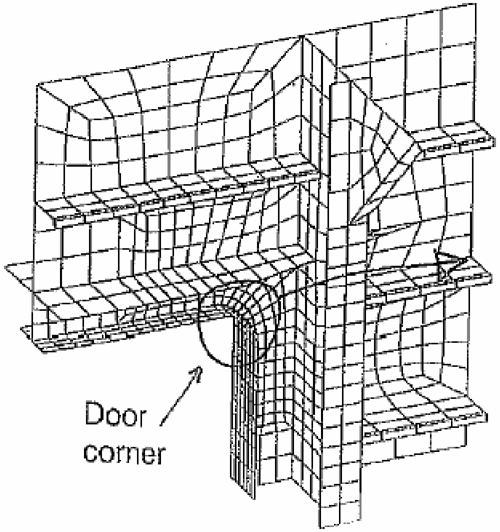


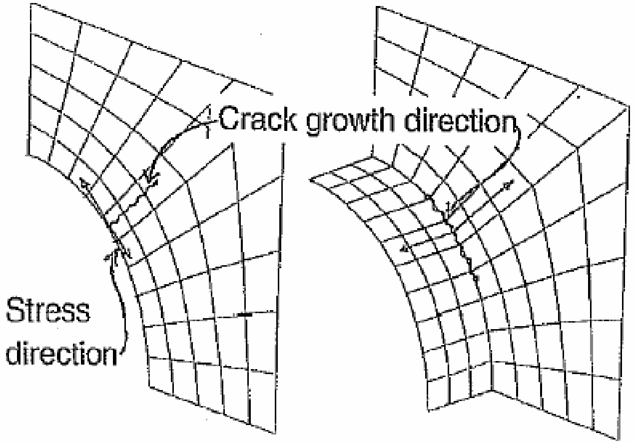
Structure modeling of

Semi-submersible platform


Analyzed deck girder


Submodel of deck girder

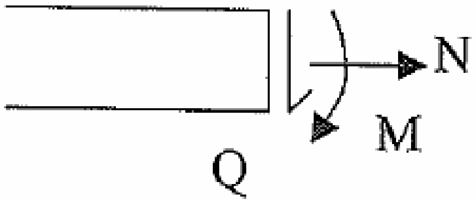




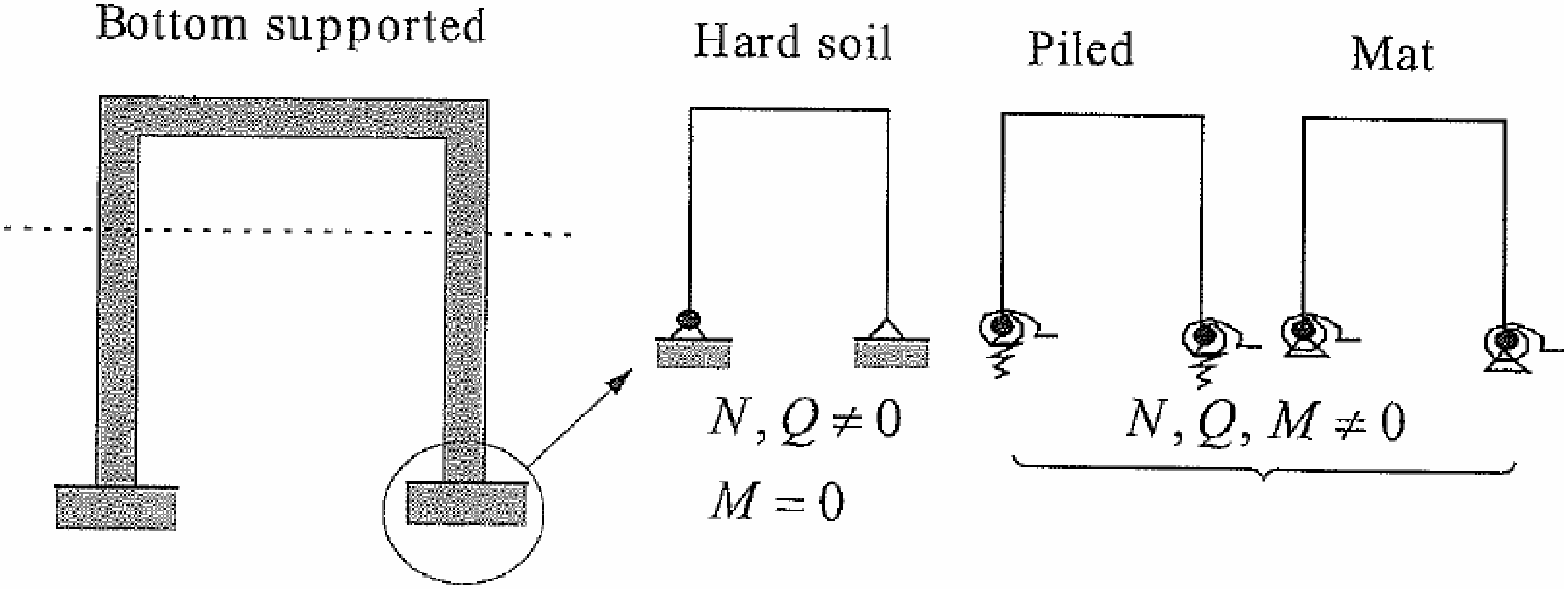
Alternative door corner designs

Frame structures

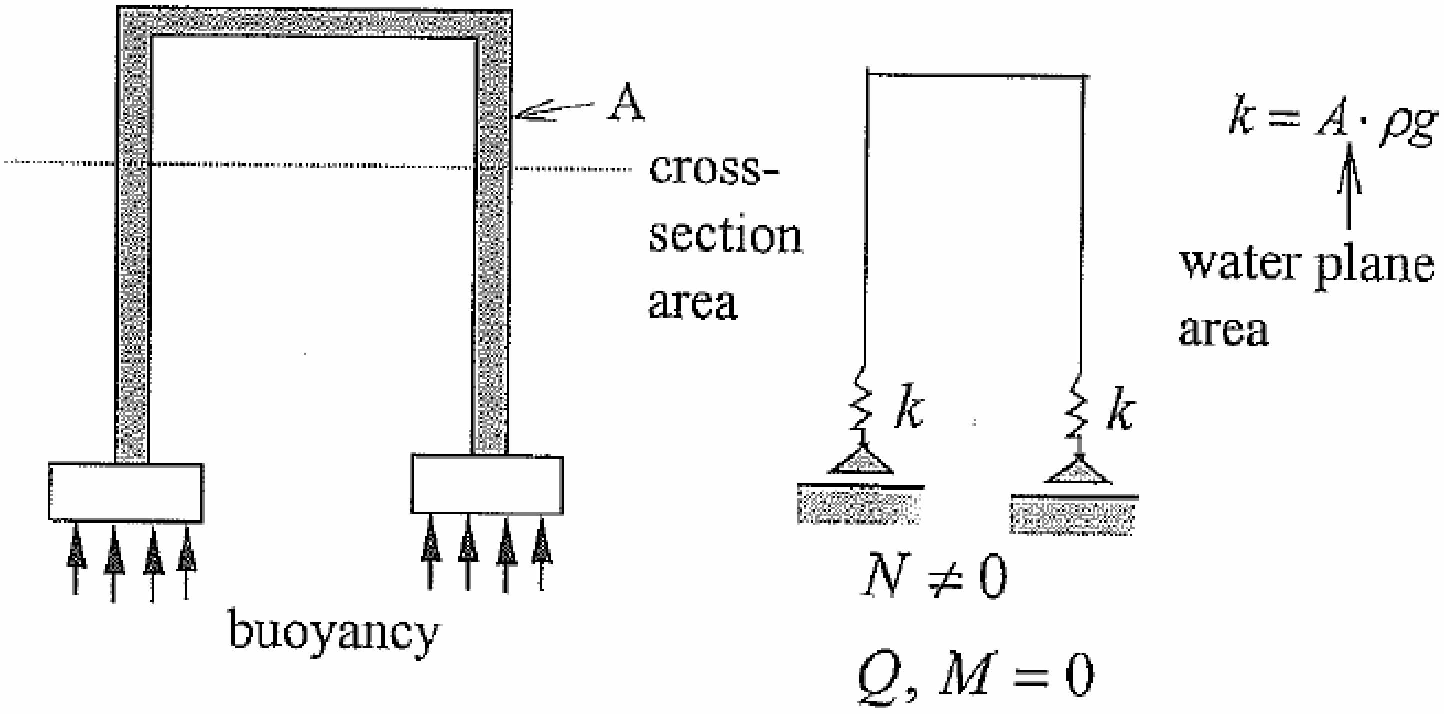
- Load effect: Axial force, shear force, bending moment



- Boundary conditions



Floating



$k = A \cdot \rho g$

$N \neq 0$

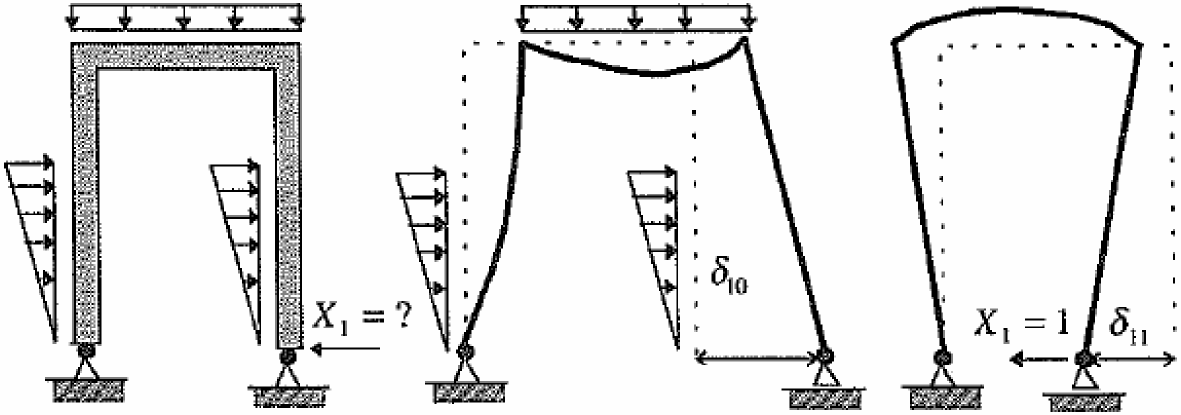
$Q, M = 0$

Analysis

- Statically determinate
- Statically indeterminate
  - – displacement method
  - – unit load method

Bottom - Supported Structure

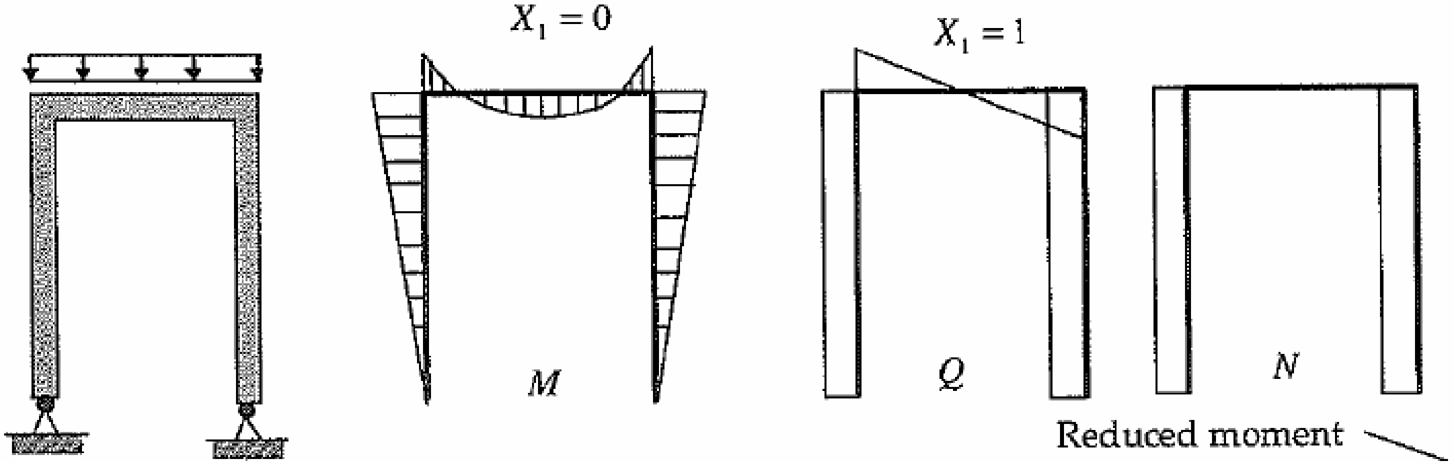
Frame: one time statically indeterminate
- determine X_1 by unit load method!

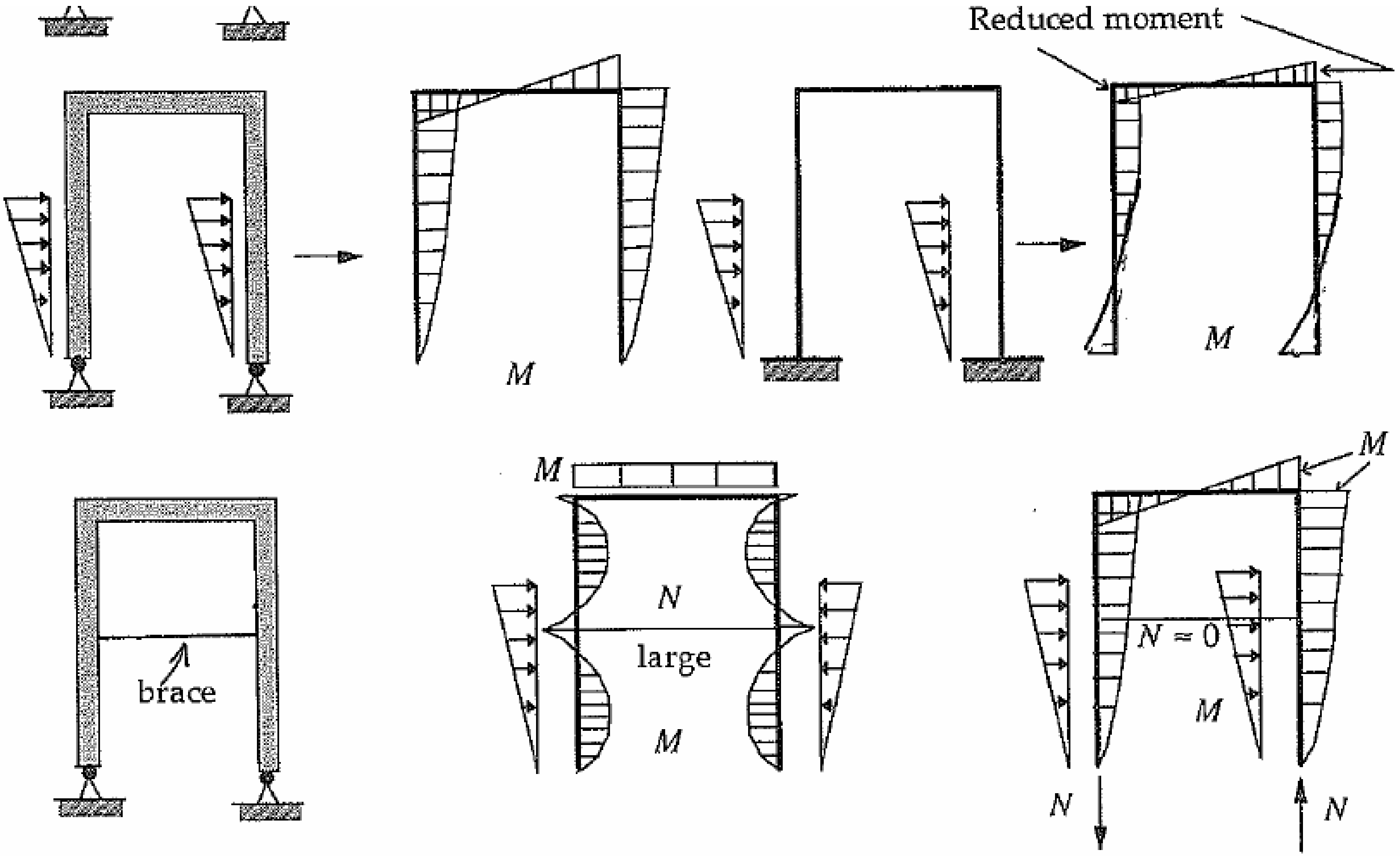


$$\delta_{11} \cdot X_1 + \delta_{10} = 0$$

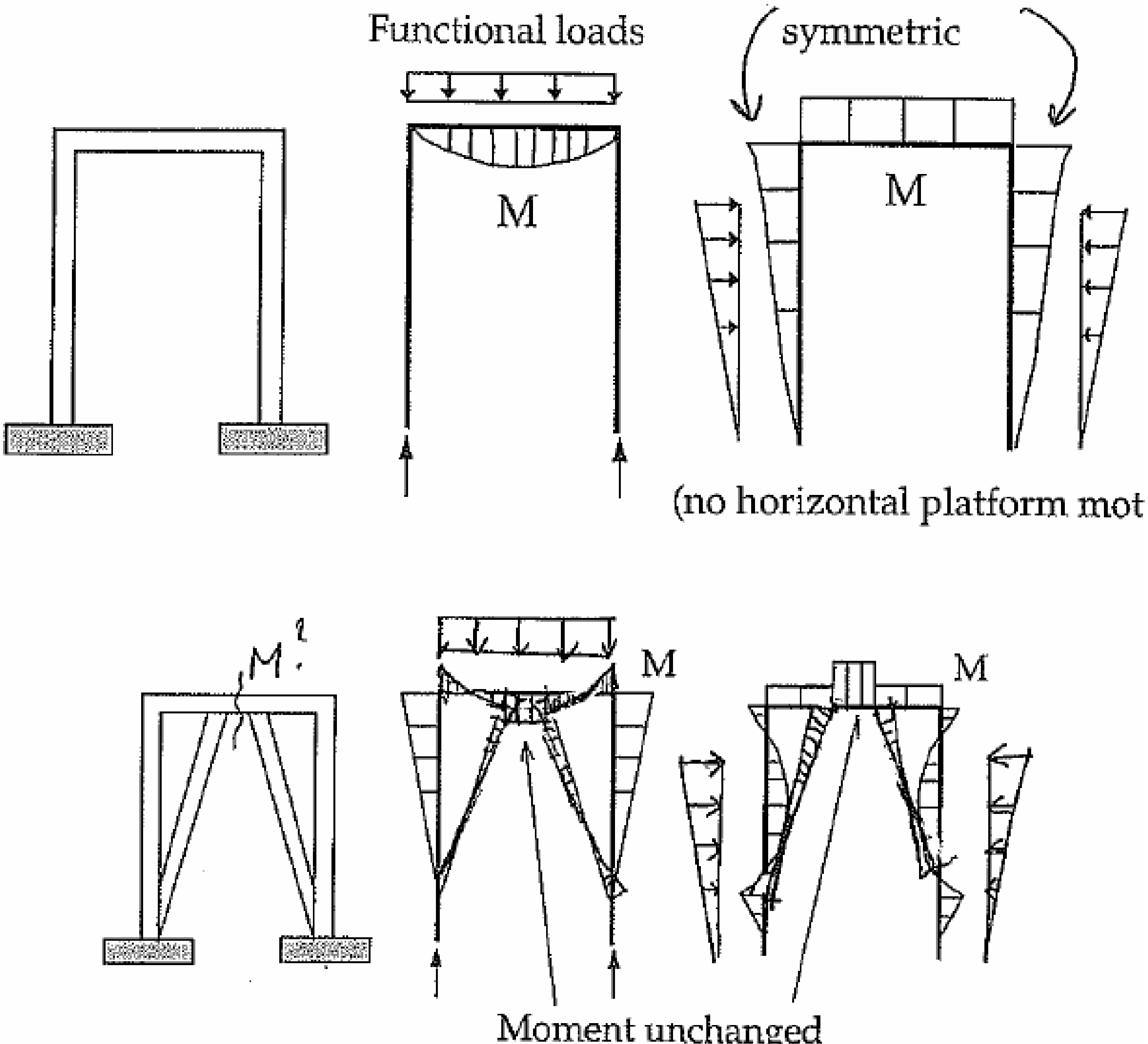
$$\Rightarrow \qquad X_1 = -\frac{\delta_{10}}{\delta_{11}}$$

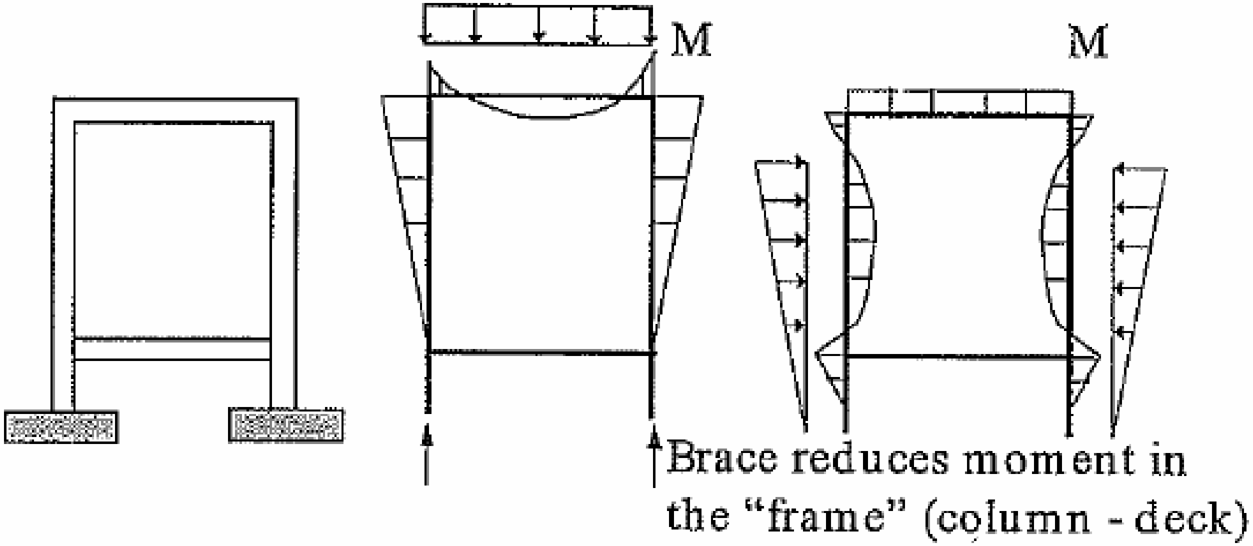
$$\delta_{ij} = \int \frac{M^i \cdot M^j}{EI} d\ell$$



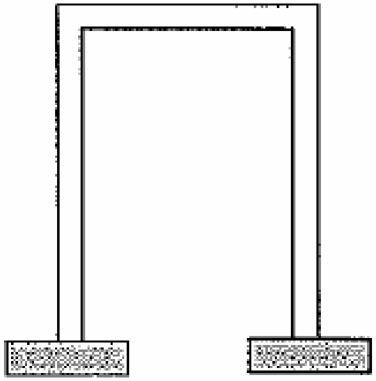

Reduced moment
M
M
M
brace
N
large
M
M
N ≈ 0
M
N
N

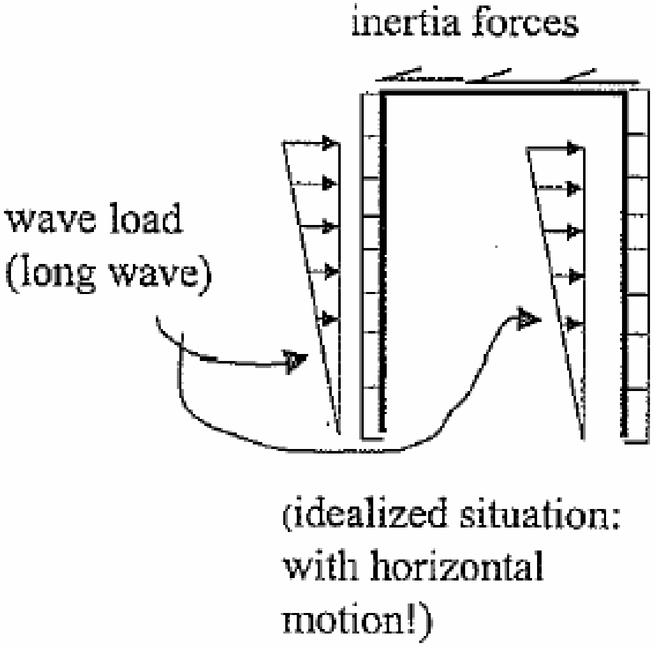
Floating platform





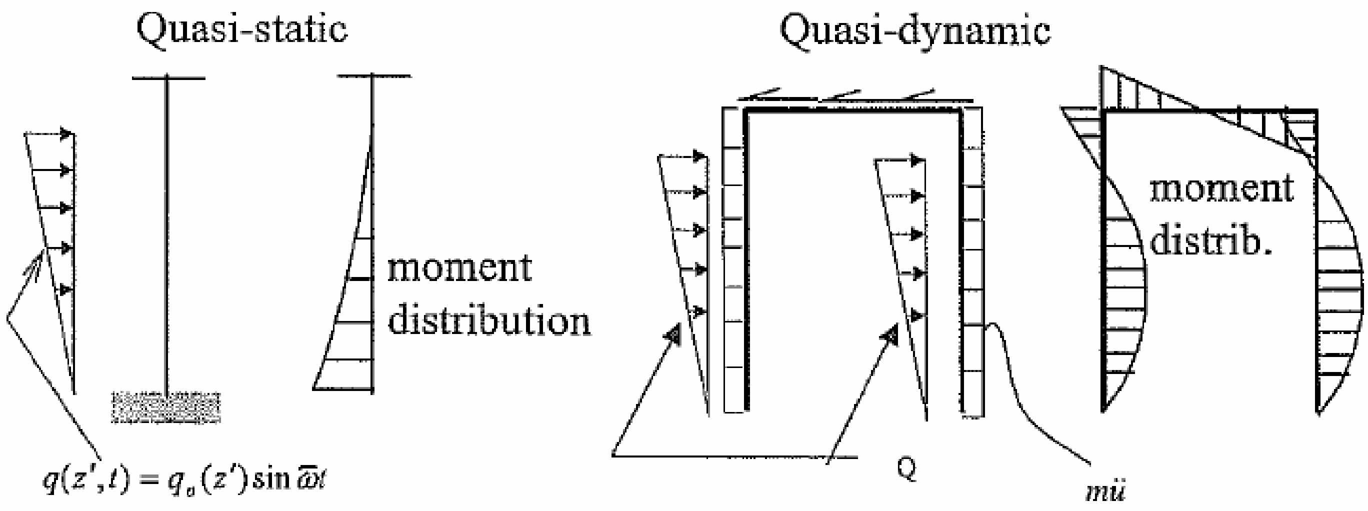
Brace reduces moment in the "frame" (column - deck)





(idealized situation: with horizontal motion!)

Summary of load effect analysis



Generalization

- excitation force
- inertia forces, damping forces
- elastic forces

Dynamic load effects !

$m\ddot{u}$

$c\dot{u}$

Time domain analysis

If an accurate assessment of dynamics is to be obtained, the equation of motion has to be solved in the time domain.

$$m\ddot{x}(t) + c\dot{x}(t) + k\,x(t) = q(t)$$

It is not easy to find a very precise way to perform such an analysis. Most experience is gathered for structures essentially behaving quasistatic. Norsok N-003 gives some guidance.

DYNAMIC ANALYSIS

- A dynamic analysis is normally mandatory for every offshore structure, but can be restricted to the main modes in the case of stiff structures.

Dynamic Model

- local joint reinforcements and eccentricities may be disregarded.
- masses are lumped at the member ends.
- the foundation model may be derived from cyclic soil behavior.

Equations of Motion

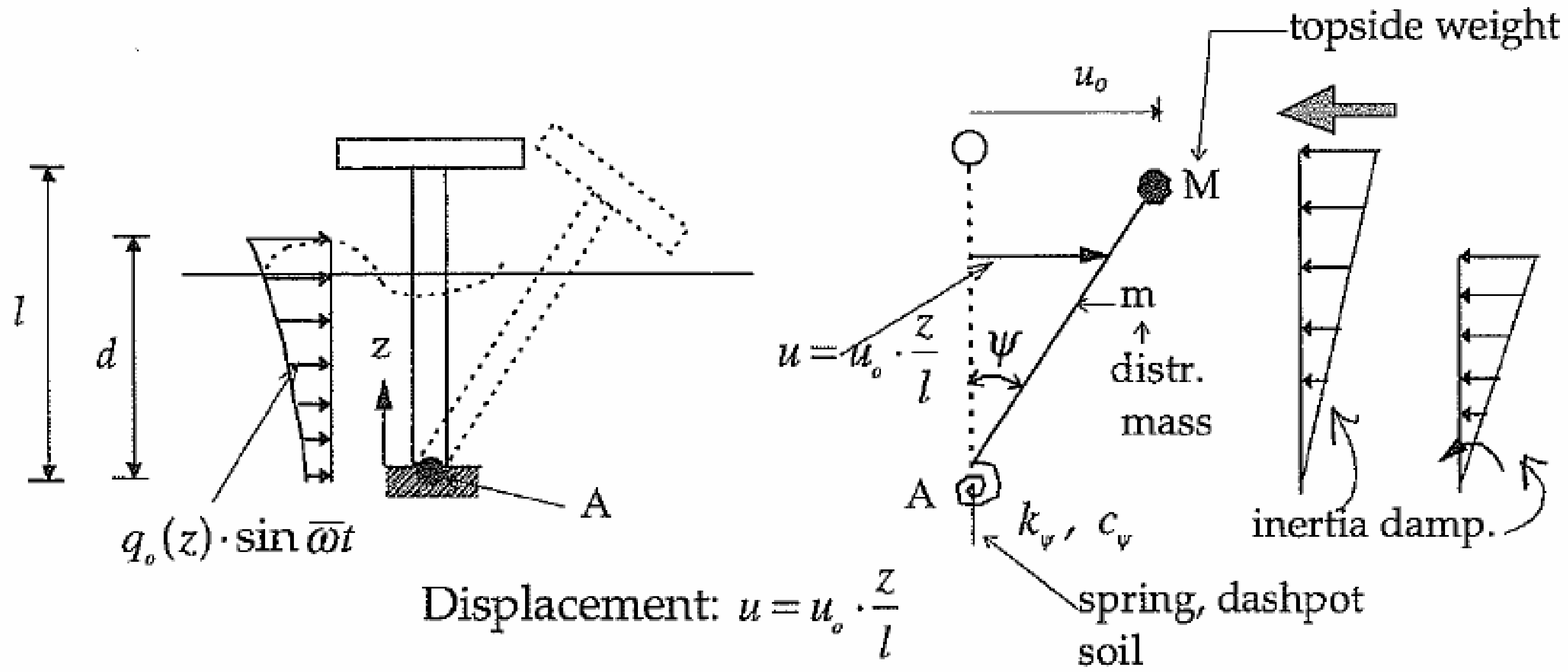
- Mass
- Damping
- Stiffness

- Free Vibration Mode Shapes and Frequencies (DAF—dynamic amplification factor)
- Modal Superposition Method
- Frequency Domain Analysis
- Time Domain Analysis

Direct Integration Methods

- Direct step-by-step integration of the equations of motion is the most general method and is applicable to:
- non-linear problems involving special forms of damping and response-dependent loadings.
- responses involving many vibration modes to be determined over a short time interval.

Chapter 5
Linear Dynamic Analysis
Dynamic analysis - hinged tower



Displacement: $u = u_o \cdot \frac{z}{l}$

External loads: waves
Inertia forces: masses, added mass
Damping: viscous hydrodynamic damping, soil c_ψ
Stiffness: structure (here; neglected EI ~ ∞)
soil (k_ψ) flexibility
buoyancy (neglected here)

Dynamic equilibrium

$$\sum M_A = 0$$

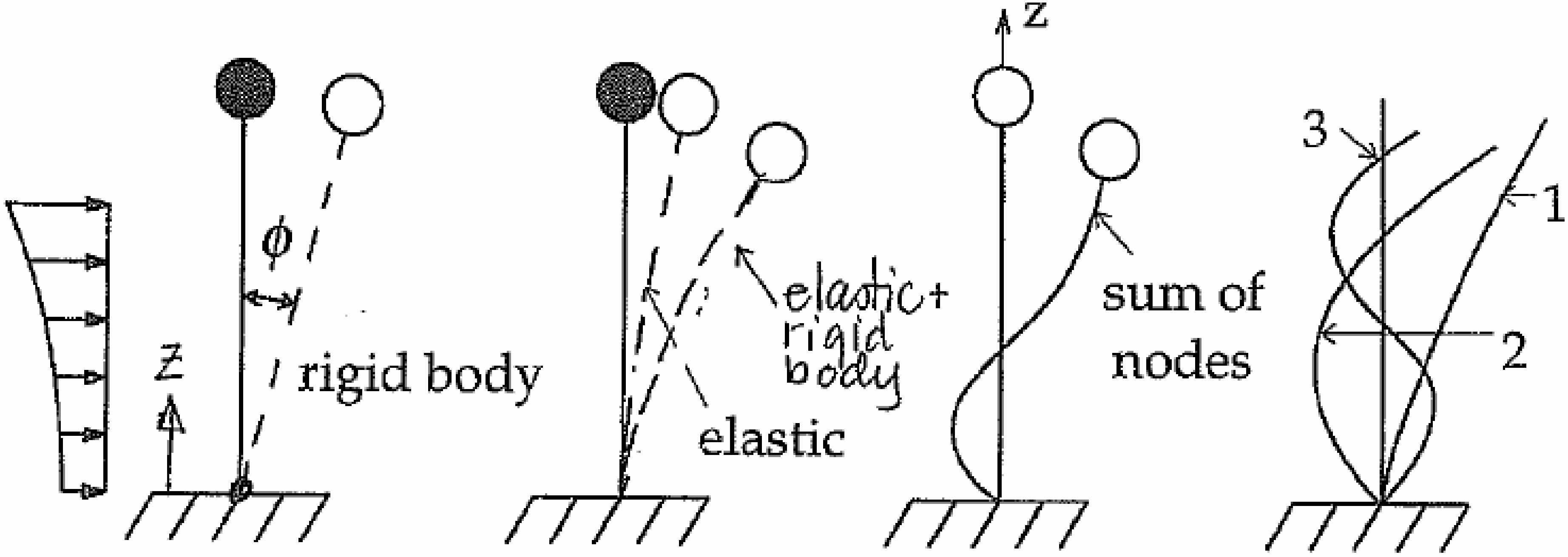
$$(M\ddot{u}_o)l + \int_0^l (m\ddot{u})z\,dz + \int_0^d (c\ddot{u})z\,dz + c_\psi \frac{\ddot{u}_0}{l} + k_\psi \frac{u_0}{l} - \overbrace{Mgu_o - mgl\frac{u_0}{2}}^{\text{"P-}\delta\text{ effect"}}$$

$$= \left(\int_0^d q_o(z)z\,dz\right)\sin\overline{\omega}t$$

negative effect

Alternative dynamic systems

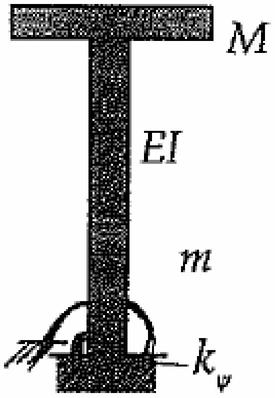
- Elastic deformation in the structure - and rigid soil.



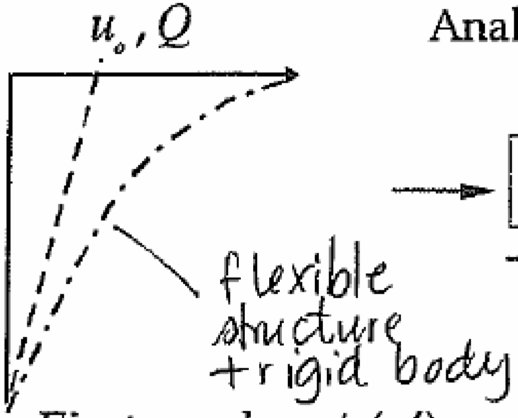
General

$\phi_i(z)$
ω_i

Simplified calculation of ω_1 for tower structure

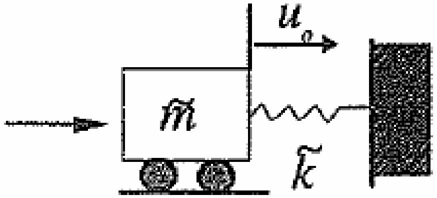


stiffness mass



First mode, $\phi_1(z')$

Analogous system



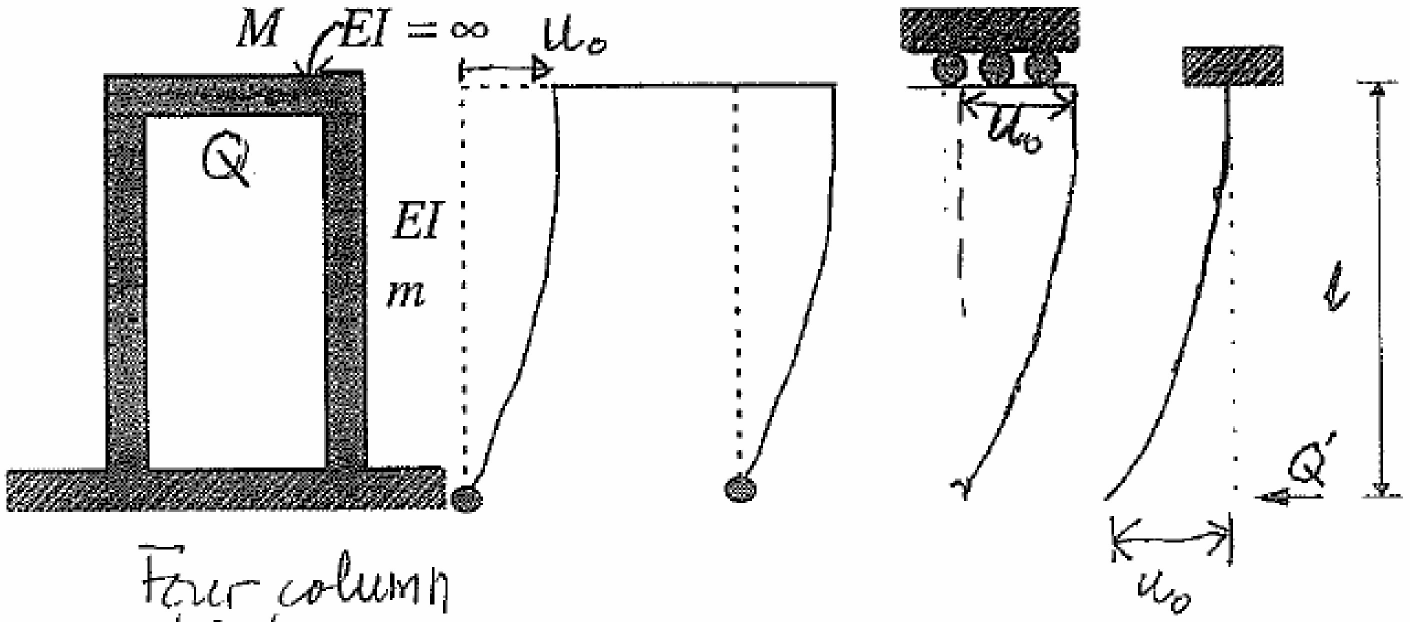
$$\omega = \sqrt{\frac{\tilde{k}}{\tilde{m}}}$$

$\tilde{k}$: Def. : $Q = \tilde{k} \cdot u_o$ Given $Q \Rightarrow$

$$u_o = \left(\frac{Q \cdot l}{k_\psi}\right) \cdot l + \frac{Q \cdot l^3}{3EI}$$

$$\tilde{k} = \frac{1}{\left[\frac{l^3}{3EI} + \frac{l^2}{k_\psi}\right]},$$

$$\tilde{m} = M + \alpha \cdot m \cdot l; \qquad \alpha = ?$$



Four column structure

Stiffness:

$$Q = \tilde{k} \cdot u_o$$

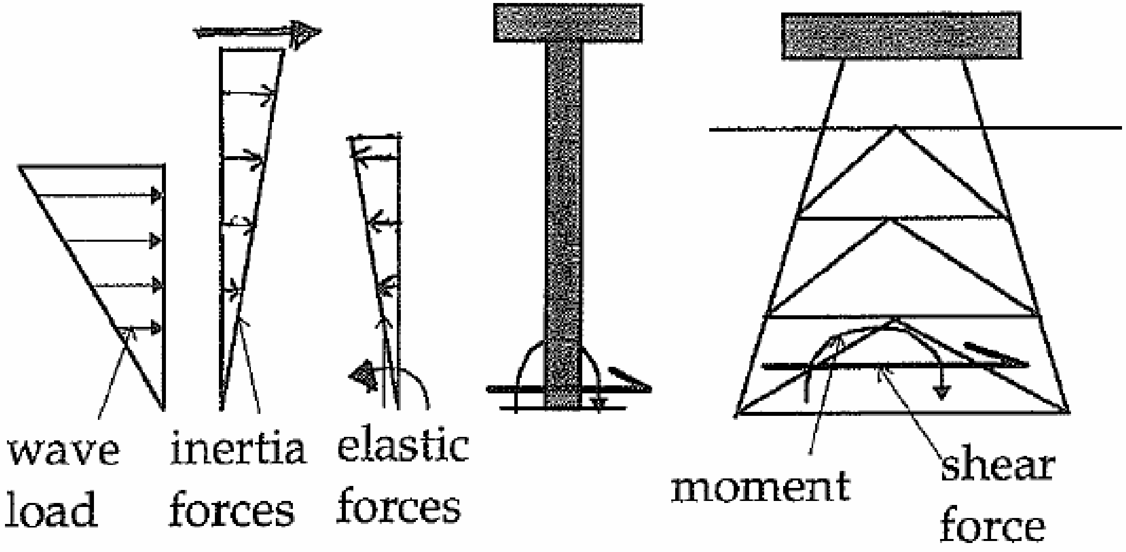
$$u_o = \frac{Q' \cdot l^3}{3EI}$$

$$Q' = \frac{Q}{4}$$

$$\Rightarrow \tilde{k} = \frac{12EI}{l^3}$$

Mass: as before

Loads

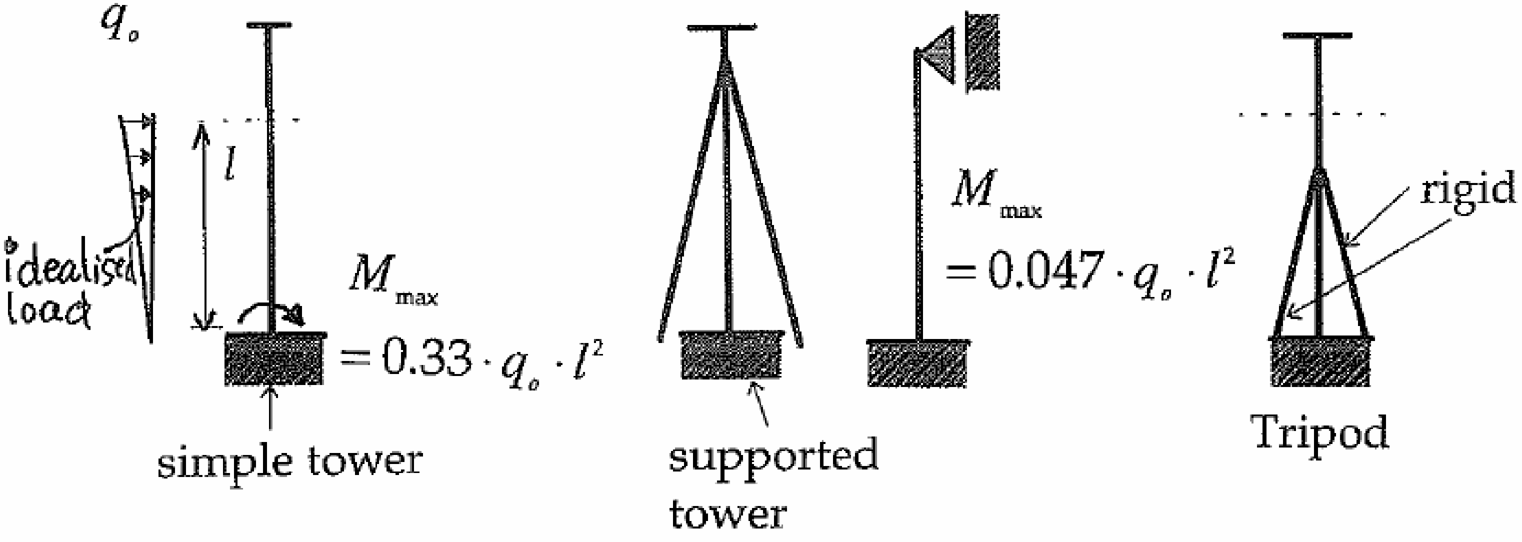


- Static moment increases with water depth
- Eigenfrequency decreases with depth
  - ⇒ increased dynamic amplification

Dynamic effects

Would first be important for moderate responses (with $T_1 = 4$s, wave length $\lambda_1 \cong 1.56\, T_1^2 \approx 25$ m , $H = 2.5$ m)
That is for loads / responses which are important for fatigue.

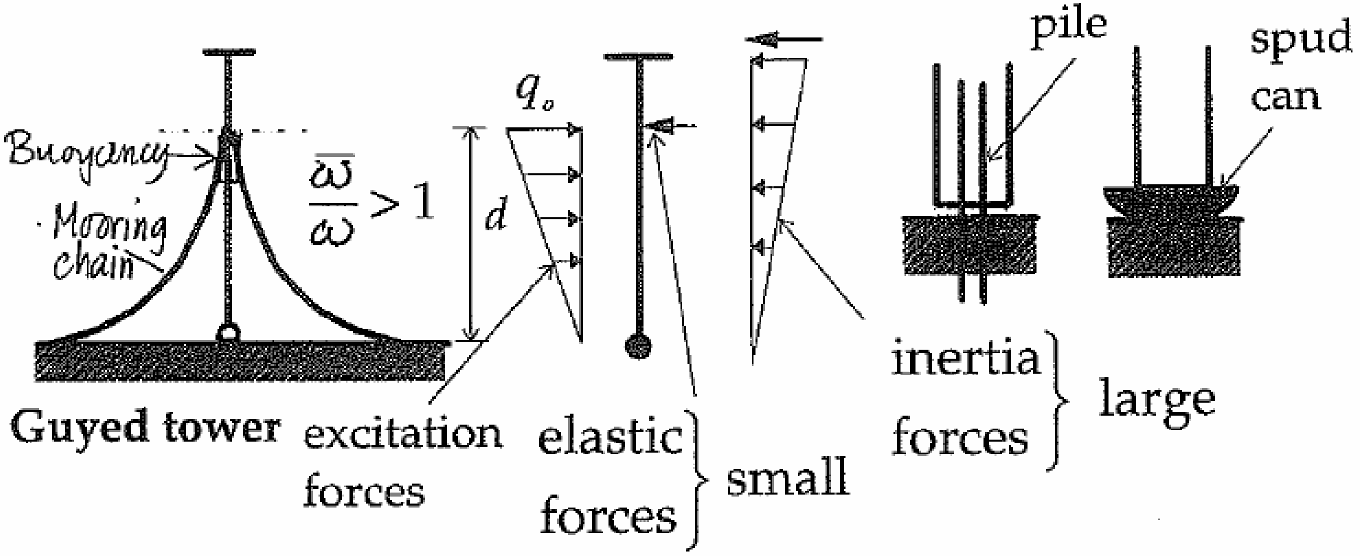
Alternative designs - Platform concepts

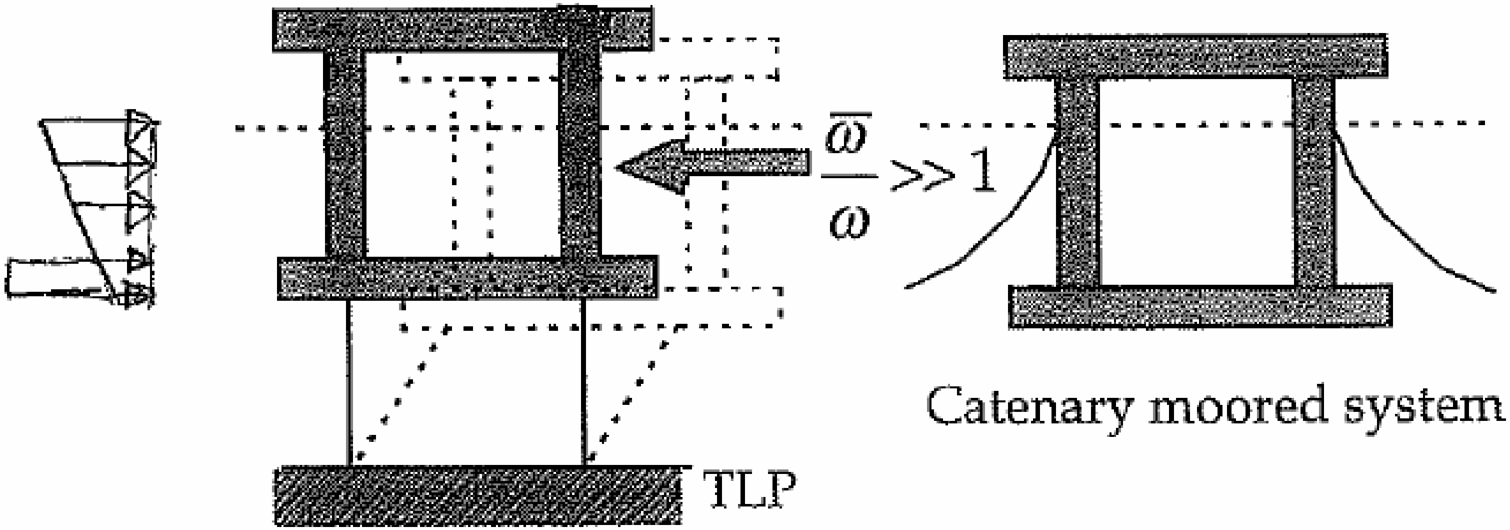


$M_{max} = 0.33 \cdot q_o \cdot l^2$

$M_{max} = 0.047 \cdot q_o \cdot l^2$

Static behavior (predominantly elastic reaction forces)





Dynamic behavior (predominantly inertia reaction forces)

CONCLUDING SUMMARY

- The analysis of offshore structures is an extensive task.
- The analytical models used in offshore engineering are in some respects similar to those used for other types of steel structures.

- The verification of an element consists of comparing its characteristic resistance(s) to a design force or stress.
- Simple rules are available for preliminary member sizing.
- Static in-plane analysis is always carried out at the early stage of a project to size the main elements of the structure.

Thank You

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