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SIMULATION AND COMPUTATION OF OSCILLATION AND STABILITY OF HAMMER-PONTOON SYSTEMS

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ABSTRACT. Hammer pontoon systems are usually used for pile-driving of onshore construction. The systems are constantly acted upon by marine wave, wind and current and have to be fixed by moorings. In this paper, on the basis of software ALASKA the system is simulated as dynamics of multi-body systems. Its natural frequencies and mode shapes are computed in order to avoid resonant phenomena by the change of design parameters.

The vibration displacement at any point of the system is calculated for estimation of technical stability of the system. The reaction forces at joints between bodies and its inertial forces are obtained for calculation of system strength of material. The ambient exciting loads are regarded as deterministic forces and as stochastic ones. In the latter case, the load is given as spectral density function and it is necessary to calculate probability characteristics of system responses. An example is investigated for illustration.

1. Introduction

A Hammer-pontoon system consists of a pontoon, a hydraulic hammer, a hammer-tower creating the direction for motion of the hammer and some equipment for its working such as pile-driving or changing working places (Fig. 1). When the hammer-pontoon system is working, it is fixed by moorings and the hammer-tower is in high position, otherwise the hammer-tower is in lower position.

The hammer-pontoon system is usually used for foundation pile-driving of onshore construction. The system is always under action of waves, wind and current.

On the basis of software ALASKA (Advanced Lagrangian Solver in Kinetic Analysis) developed by Institute of Mechatronics, TU-Chemnitz, Germany, the hammer-pontoon system is modeled as dynamics of multi-body system and its natural frequencies and mode shapes are computed. The dynamical loading of wave, wind and current on the pontoon is calculated and therefore it is able to determine the ambient oscillation of the system for the cases of deterministic and stochastic loads.

From these results the stability conditions of the system can be deduced for the case of existing moorings or not.

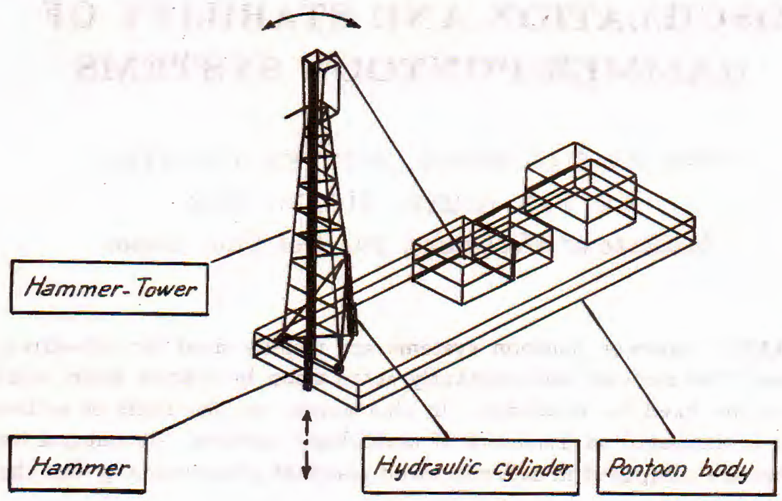

Fig. 1

2. Modeling of hammer-pontoon system

The hammer-pontoon system is regarded as a buoyant body, therefore the problem has been investigated in several papers and books [1, 2], where the system is subjected to action of Archimedes force and wave, wind and current loads.

The general multiple degree of freedom equations of motions for a stationary floating body in gravity waves can be formulated as matrix equations in the six rigid body degrees of surge, sway, heave, roll, pitch and yaw described by column vector $\mathbf{X}$, although additional degrees of freedom (such as structural deformation) can be incorporated, if required.

For the hammer-pontoon system the basic equation can be written simply as

$$(\mathbf{M}+\mathbf{M}_A)\ddot{\mathbf{X}}+\mathbf{B}\mathbf{X}+(\mathbf{K}+\mathbf{K}_m)\mathbf{X}=\mathbf{F}(t), \tag{2.1}$$

where $\mathbf{M}$, $\mathbf{M}_A$ are the (6×6) coefficient matrices quantifying structure physical mass, added mass; $\mathbf{K}$ and $\mathbf{K}_m$ are (6×6) stiffness matrices contributed by the hydrostatic and mooring restoring forces acting on the system; $\mathbf{B}$ is matrix of damping coefficient and $\mathbf{F}(t)$ is exciting force of waves, wind and current.

Notice that the matrices $\mathbf{M}_A$ and $\mathbf{B}$ are frequency dependent values and $\mathbf{K}_m$ is non-linear stiffness,

$$\mathbf{K}_m(\mathbf{X}) = \begin{cases} 0 & \text{if} \quad \ell(\mathbf{X}) - \ell_0 \leq 0, \\ \mathbf{K}_1[\ell(\mathbf{X}) - \ell_0] & \text{if} \quad \ell(\mathbf{X}) - \ell_0 > 0, \end{cases}$$

where $\ell(\mathbf{X})$ is the length of mooring line in recent time, ℓ_0 - initial length of the mooring line, $\mathbf{K}_1$ - constant coefficient, $\mathbf{F}(t)$ - exciting forces. Therefore equation (2.1) expresses complicated phenomena of non-linear oscillation. It is able to solve the problem not directly from equation (2.1) but by simulation method.

On the basis of software ALASKA for dynamics of multi-body system, the hammer-pontoon system can be simulated as follows:

The system is regarded to consist of 10 rigid bodies connected with each other by some ideal joints or damper-spring elements (Fig. 1).

The Archimedes force is replaced by system of damper-springs connecting node points on mesh at bottom of the pontoon with the points at sea bed. When the pontoon is in motion, the positions of points at sea bed have to be changed so that the damper-spring elements are always vertical. If M is the hammer-pontoon system mass, $\Delta\ell$ is the height of submerged part of the system, n is number of damper-spring elements, then the stiffness K of a spring is determined by the formula

$$K = \frac{M \cdot g}{n\Delta\ell}. \tag{2.2}$$

The damping coefficient is determined following "Rules for Design" of DnV [3].

Anchoring lines must keep a floating structure at a given position when it is subjected to environment loads. The anchoring lines are modeled by damper-spring elements with greater stiffness. When the distance between two anchoring end points is less than initial distance then the spring force is equal to zero. The position of hammer-tower is controlled by cylinder-piston system depended on working regime of the hammer-pontoon system. When the system is not working and in motion the hammer-tower is put lower and the anchoring lines are taken off. The hammer-pontoon system has been modeled as multi-body system under action of environment loads and working equipment forces. In principle the working equipment forces have light influence on vibration of the system, therefore the investigation of motion of the system is concentrated under action of environment loads.

The technical stability of the system is understood as follows: If under action of the ambient and working equipment loads the roll vibration of the system is not so big that water could come over pontoon board, the system is said to be stable.

The conception will be used in the example with roll angle of the system computed by ALASKA

3. Computation of environment loads acting on the hammer-pontoon system

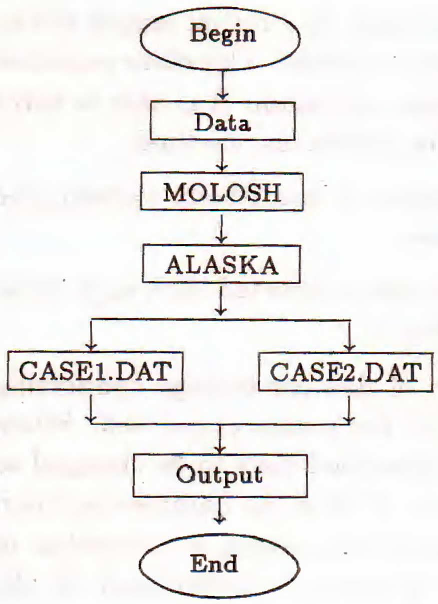

Fig. 2

In order to apply software ALASKA to hammer-pontoon system after modeling the system, it is necessary to calculate the environment loads acting on it. For this purpose the program MOLOSH (Motion and Load of Ship) has been applied and its results are used as input for software ALASKA. The input data for MOLOSH are parameters of environment such as the height and length of waves, the velocity of wind and current; the dimensions of pontoon: the length of pontoon, submerged part, the height of mass centre.... The output of the program are the forces acting on surge, sway and heave directions and the moments caused pitch, roll and yaw motion.

The block scheme for application of program MOLOSH and software ALASKA to hammer-pontoon system is shown in Fig. 2.

4. Simulation of hammer-pontoon system by ALASKA

After receiving resultant forces and moments from program MOLOSH and modeling in previous section of hammer-pontoon system, it is able to write some input programs for the system and apply ALASKA to simulation of system motion. The input programs are written for 2 cases.

Case 1: Pontoon is fixed by mooring lines and hammer-tower is in high position and the system is subjected to environment loads.

The input file named by CASE1.DAT has a structure as on Fig. 3.

Case 2: The hammer-pontoon system is moving with velocity V, the hammer-tower is in the lowest position.

The input file named by CASE2.DAT has a structure similar to the first case. In these cases the include files from 1 to 10 describe the rigid bodies (the main component parts of the pontoon-hammer system), Cable.inc, describes the mooring lines.

The files: Sdforce.inc, Wavefor.inc, Windfor.inc, Flowfor.inc express Archimedes force, wave, wind and flow forces respectively acting on the pontoon. Result.inc is file described required results.

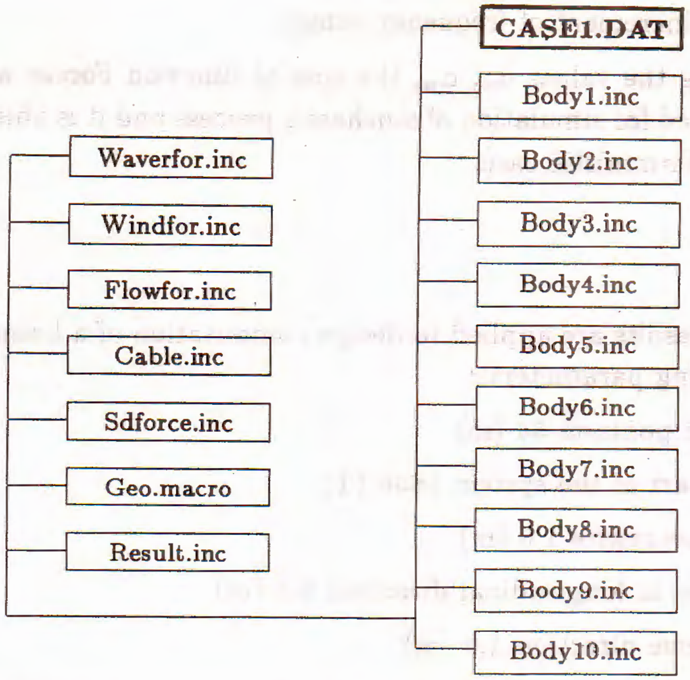

Fig. 3

Outputs from ALASKA can be displacement, velocity and acceleration of arbitrary point of the system, reaction forces of joints in the form of numerical list or graphic, and also natural frequencies and mode shapes of the system. From these results it is possible to calculate all forces such as inertial forces, moments and reaction... for estimation of the strength of materials for hammer-tower or pontoon.

In both cases the action of wave, wind and current on the pontoon could be investigated in the form of deterministic or stochastic forces. If the waves regime is regarded as random waves characterised by function of spectral density such as Pierson-Moskowitz spectrum or JONSWAP spectrum then in results of program MOLOSH the forces would be given by functions of spectral density $S(\omega)$.

In this case notice that a sample of stochastic process could be expressed in the from

$$u(t) = \sum_{n=1}^{\infty} u_n(t) = \sum_{n=1}^{\infty} a_n \cos(\omega_n t + \alpha_n), \tag{4.1}$$

where a_n and ω_n are n^{th} amplitude and frequency of the sample, α_n is random number with uniform distribution on interval $(0, 2\pi)$. The value a_n is calculated by the formula

$$a_n = 2\sqrt{S(\omega_n)\Delta\omega}, \tag{4.2}$$

where $\Delta\omega$ is equal increment of frequency range.

After obtaining the values a_n, α_n, the special function Forcos and Forsin in ALASKA can be used for simulation of stochastic process and it is able to calculate by ALASKA as deterministic case.

5. Example

The previous results are applied to design computation of a hammer-pontoon system with following parameters:

- Length of the pontoon 54 (m)
- Submerged part of the system 1836 (T)
- Height of mass centre 1.6 (m)
- Inertial radius in longitudinal direction 8.3 (m)

  and transverse direction 1.6 (m)

  and some another parameters for wave, wind and current are given.

The graphic results are obtained for

+ The first mode shape (Fig. 4)

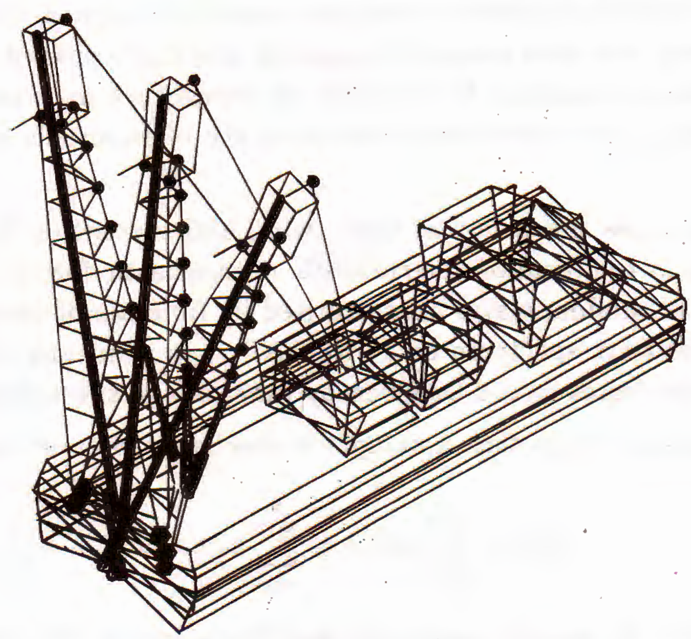

Fig. 4

+ The tensional force of mooring line (Fig. 5)

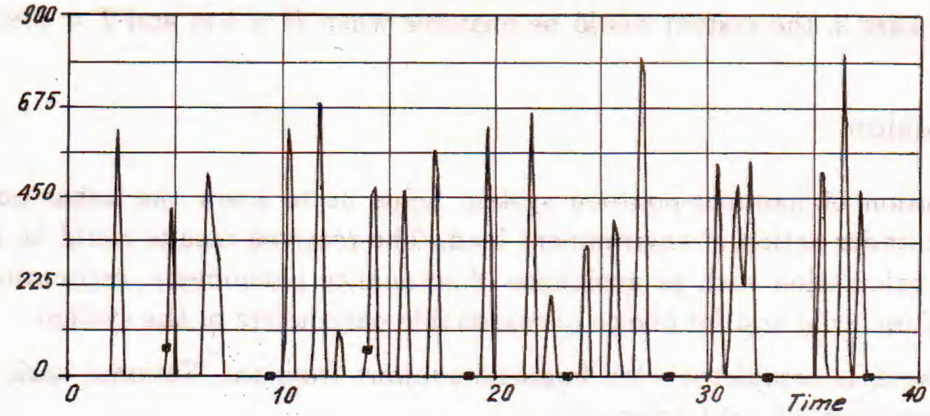

Fig. 5

+ The reaction forces between pontoon and hammer-tower (Fig. 6)

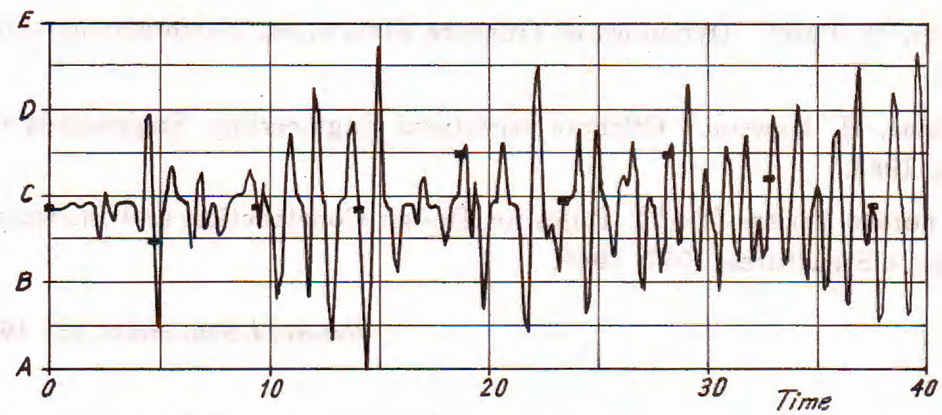

Fig. 6

+ The roll angle of the pontoon in case 2 with wave height H=5m, wave period $T = 2.48\,\mathrm{s}$ (Fig..7)

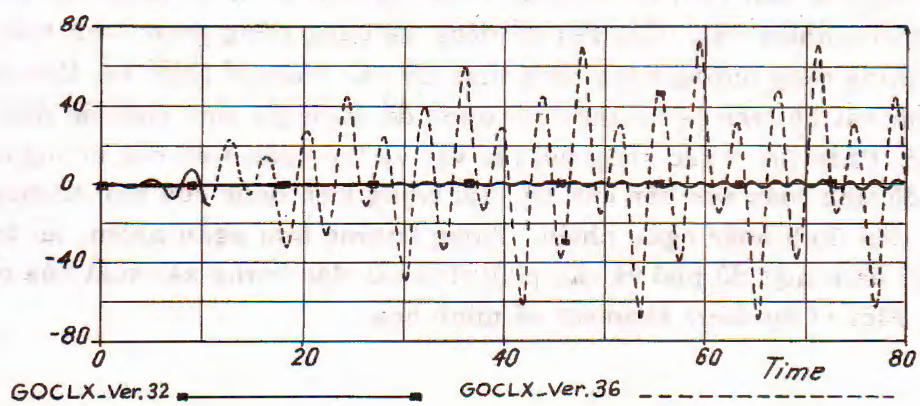

Fig. 7

In the case 2, the system would be unstable when $H = 5\,\text{m}$ and $T = 5.85\,\text{s}$.

6. Conclusion

Simulation of hammer-pontoon system helps us to know the behaviour of the system under action of environment load. The received results could be used for design calculation such as avoidance of resonance phenomena, estimation of strength of material and for choice of reasonable parameters of the system.

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MÔ PHỎNG VÀ TÍNH TOÁN DAO ĐỘNG VÀ ỔN ĐỊNH CỦA HỆ XÀ LAN-BÚA MÁY

Hệ xà lan búa máy thường dùng để đóng cọc ở các công trình ven biển. Hệ này chịu tác dụng thường xuyên của sóng, gió, dòng chảy và phải cố định bằng dây neo. Trong bài này, trên cơ sở phần mềm ALASKA, hệ đã được mô phỏng theo mô hình hệ nhiều vật. Các tần số riêng và dạng riêng được tính toán để tránh hiện tượng cộng hưởng bằng cách thay đổi các tham số thiết kế. Dao động của một điểm bất kỳ trên hệ có thể tính được để đánh giá tính chất ổn định kỹ thuật của hệ. Phản lực ở các khớp nối các vật và lực quán tính của chúng cũng nhận được để tính toán sức bền của hệ. Tải trọng kích động của môi trường có thể coi như tiền định hoặc ngẫu nhiên. Trong trường hợp ngẫu nhiên, tải trọng được cho bởi hàm mật độ phổ và cần phải tính các đặc trưng xác suất của phản ứng của hệ. Một ví dụ được khảo sát để minh họa