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CABLE-STAYED-BRIDGES UNDER SUDDEN FAILURE OF STAYS: THE 2D PROBLEM

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Abstract. *A significant problem, sprung from the praxis, is the failure of cables. There are a lot of causes that can lead to sudden failure of a cables. Corrosion, continuous friction or abrasion, progressive and extended crevice created by fatigue, and finally an explosion caused by a sabotage or an accident are some of the causes that can lead to the failure of one or more cables. This paper deals with the sudden cables' failure of a special form of c-s-bridges, having one line of cables, anchored at the central axis of the deck's cross-section. The analysis is carried out by the modal superposition method using the analytical method exposed by the authors in previous publications.*

1 INTRODUCTION

Cable stayed bridges have been known since the beginning of the 18th century, but they have been of great interest only in the last fifty years, particularly due to their special shape and also because they are an alternative solution to suspension bridges for long spans. The main reasons for this delay were the difficulties in their static and dynamic analysis, the various non-linearities, and the absence of computational capabilities, the lack of high strength materials and the lack of construction techniques. There is a great number of studies, concerning the static behaviour [1-3], the dynamic analysis [4-7], or the stability of cable-stayed bridges [8,9].

A significant problem, which arose from the praxis, is the failure of cables. There are a number of causes that can lead to sudden failure of cables. Corrosion, continuous friction or abrasion, progressive and extended crevice created by fatigue, and finally an explosion caused by a sabotage or an accident are some of the causes that can lead to the failure of one or more cables.

The failure of one or more cables, causes a redistribution of the forces and stresses, not only on the remaining stays but also on the bridge-deck and on the pylons.

The existing codes and recommendations [10, 11] confront this accidental situation by multiplying with a dynamic amplification factor (DAF) the forces and stresses, obtained by the static analysis of the bridge. These guidances, after experimental tests [12] and FEM analysis [13] proved inadequate [14]. A lot of recent publications [15,16], showed that the advised factors are unsafe.

This paper deals with the sudden cables' failure of a special form of c-s-bridges, which has one line of cables anchored at the central axis of the deck's cross-section. The analysis is carried out by the modal superposition method using the analytical process exposed by [17-19]. Characteristic examples are solved and useful diagrams and plots are drawn, while interesting results are obtained.

2 ANALYSIS

The following analysis concerns a cable-stayed bridge with one line of cables, anchored at the central axis of the deck's cross-section.

2.1 Pylon's stressing

The deformation f(z) at the random point A(z) of a pylon of height h is given by the relation:

$$\left. f = f_o(z) \cdot P_x \,, \quad \text{where:} \quad f_o(z) = \frac{h^3}{3E_p I_p} \right\} \tag{1}$$

2.2 The isolated cable

Let us consider the bridge of Figure 2, with one line of cable, anchored at the center of the deck's cross-section.

The bridge, is stayed by ρ cables at the left, and κ at the right of pylon a, and by κ cables at the left and ρ cables at the right of pylon b.

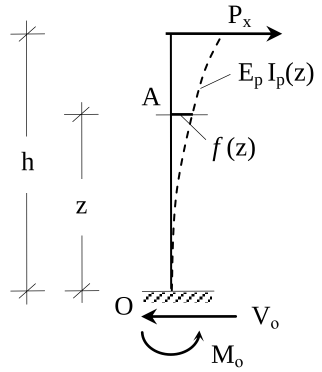


Figure 1: The deformed pylon.

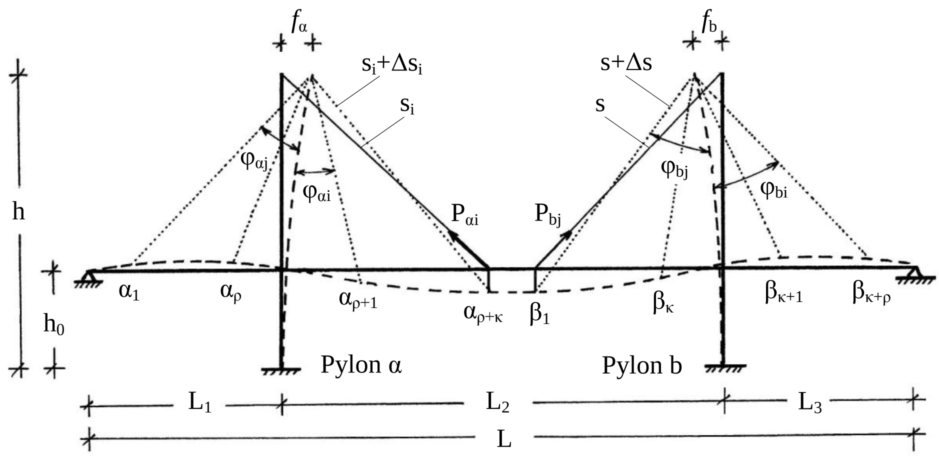


Figure 2: Cable-stayed bridge of three spans

For the cable "i" of Figure 2 we finally get:

$$\frac{s_i P_i}{E_c A_i} + f \sin\varphi_i = w_i \cos\varphi_i \tag{2}$$

where E_c is the modulus of elasticity of the cables and A_i is the cross-section's area of the cable i.

3.2.1 Thin arrangement of cables

The total deformation at the top of the pylon, because of the acting horizontal forces, is:

$$\begin{aligned} & f(h) = f_o(h)\left[\sum_i P_i \sin\varphi_{ai} - \sum_j P_j \sin\varphi_{aj}\right] = f_o \Phi_a \\ & \text{where : } \quad \Phi_a = \sum_i P_i \sin\varphi_{ai} - \sum_j P_j \sin\varphi_{aj} \end{aligned} \tag{3.a}$$

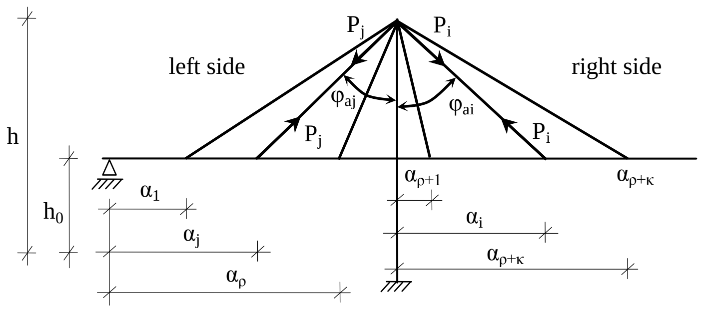


Figure 3: Symbolisms right and left the pylon.

Applying Eqs. (2.b), for both sides of the pylon we get:

$$\left.\begin{array}{ll} \text{left side} & b_{aj}P_{aj} - f_o\Phi_a \sin\varphi_{aj} = w_a \cos\varphi_{aj} \\ \text{right side} & b_{ai}P_{ai} + f_o\Phi_a \sin\varphi_{aj} = w_b \cos\varphi_{ai} \\ \text{where :} & b_{aj} = \dfrac{s_j}{E_c A_j} \quad \text{and} \quad b_{ai} = \dfrac{s_i}{E_c A_i} \end{array}\right\} \tag{3.b}$$

Multiplying the first of Eqs. (3b) by $\sin\varphi_{aj}$ and adding the ρ equations, afterwards multiplying the second of Eqs. (3b) by $\sin\varphi_{ai}$ and adding the κ equations, we obtain a couple of equations and from their subtraction we finally find:

$$\left.\begin{array}{l} \Phi_a = \dfrac{1}{1+f_o(A_{aj}+A_{ai})}\left\{\sum_{i=1}^{\kappa}\dfrac{\sin 2\varphi_{ai}}{2b_{ai}}w_2 - \sum_{j=1}^{\rho}\dfrac{\sin 2\varphi_{aj}}{2b_{aj}}w_1\right\} \\ \text{where : } A_{aj} = \sum_{j=1}^{\rho}\dfrac{\sin^2\varphi_{aj}}{b_j}, \quad A_{ai} = \sum_{i=1}^{\kappa}\dfrac{\sin^2\varphi_{ai}}{b_i} \end{array}\right\} \tag{3.d}$$

From Eqs. (3b), easily one can obtain the cables' stresses:

$$\left.\begin{array}{l} P_{aj} = \dfrac{\cos\varphi_{aj}}{b_{aj}}w_1 + f_o\dfrac{\sin\varphi_{aj}}{b_{aj}}\Phi_a \\ P_{ai} = \dfrac{\cos\varphi_{ai}}{b_{ai}}w_2 - f_o\dfrac{\sin\varphi_{ai}}{b_{ai}}\Phi_a \end{array}\right\} \tag{3.e}$$

3.2.2 Dense arrangement of cables

Let us consider next, that the cables are in a dense arrangement and that the distances δ_j and δ_i between two neighboring cables satisfy the conditions:

$$\delta_j \ll \alpha_\rho - \alpha_1 \quad \text{and} \quad \delta_i \ll \alpha_{\rho+\kappa} - \alpha_{\rho+1} \tag{4.a}$$

Then, we may consider a distributed load $q_z(x)$, applied from position α_1 to α_ρ and from $\alpha_{\rho+1}$ to $\alpha_{\rho+\kappa}$, which for instance at position "i " will be:

$$q_i(x) = \frac{1}{\delta_i}\cdot P_i \tag{4.b}$$

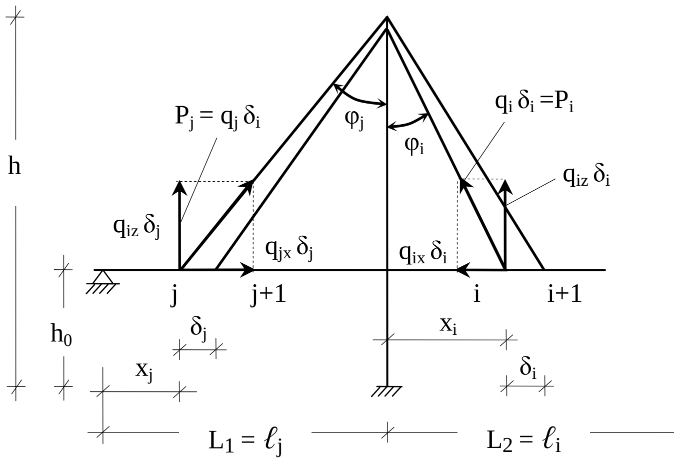


Figure 4: Dense arrangement of cables

Following the notations of Figure 4, after mathematical manipulations and through a similar process like the one of §2.3.1, we get for pylon a:

$$\left.\begin{aligned}
&q_{aj}(x) = \frac{\cos\varphi_{aj}}{b_{aj}} w_1 + f_o \frac{\sin\varphi_{aj}}{b_{aj}} \Phi_a \\
&q_{ai}(x) = \frac{\cos\varphi_{ai}}{b_{ai}} w_2 - f_o \frac{\sin\varphi_{ai}}{b_{ai}} \Phi_a \\
&\text{where : } \quad \Phi_a = \frac{1}{1+f_o(I_{aj}+I_{ai})}\left[\int_{\alpha(\rho+1)}^{\alpha(\rho+\kappa)} \frac{\sin 2\varphi_{ai}}{2b_{ai}} w_2 dx_2 - \int_{\alpha 1}^{\alpha\rho} \frac{\sin 2\varphi_{aj}}{2b_{aj}} w_1 dx_1\right] \\
&\qquad I_{aj} = \int_{\alpha 1}^{\alpha\rho} \frac{\sin^2\varphi_{aj}}{b_{aj}} dx_1 \quad , \quad I_{ai} = \int_{\alpha(\rho+1)}^{\alpha(\rho+\kappa)} \frac{\sin^2\varphi_{ai}}{b_{ai}} dx_2
\end{aligned}\right\} \tag{4.c}$$

Finally for pylon b we get:

$$\left.\begin{aligned}
&q_{bj}(x) = \frac{\cos\varphi_{bj}}{b_{bj}} w_2 - f_o \frac{\sin\varphi_{bj}}{b_{bj}} \Phi_b \\
&q_{bi}(x) = \frac{\cos\varphi_{bi}}{b_{bi}} w_2 + f_o \frac{\sin\varphi_{bi}}{b_{bi}} \Phi_b \\
&\text{where : } \quad \Phi_b = \frac{1}{1+f_o(I_{bj}+I_{bi})}\left[\int_{b1}^{b\kappa} \frac{\sin 2\varphi_{bj}}{2b_{bj}} w_2 dx_2 - \int_{b(\kappa+1)}^{b(\kappa+\rho)} \frac{\sin 2\varphi_{bi}}{2b_{bi}} w_3 dx_3\right] \\
&\qquad I_{bj} = \int_{b1}^{b\kappa} \frac{\sin^2\varphi_{bj}}{b_{bj}} dx_2 \quad , \quad I_{bi} = \int_{b(\kappa+1)}^{b(\kappa+\rho)} \frac{\sin^2\varphi_{bi}}{b_{bi}} dx_3
\end{aligned}\right\} \tag{4.d}$$

2.3 The static problem.

The equilibrium equation of the deck of a c-s-bridge, loaded symmetrically, is the following:

$$E_b I_b w_o''''(x) = p_{tot}(x) \tag{5.a}$$

where: E_b is the modulus of elasticity of the bridge deck,
I_b is the moment of inertia of the cross-section of the bridge deck,
$w_o(x)$ is the total vertical displacement of the deck under the static loads g and p.

$$p_{tot} = g(x) + p(x) - q(x,w)/\cos\varphi \tag{5.b}$$

In the last equation: g(x) is the dead load of the bridge, p(x) is the live load and q(x,w) are the forces due to the cables.

We are searching for a solution under the form:

$$w_o(x) = \sum_{i=1}^{n} c_i Z_i(x) \tag{5.d}$$

where c_i are unknown coefficients under determination and $Z_i(x)$ are arbitrarily chosen functions of x, which must satisfy the boundary conditions of the deck. In this case, are the shape functions of the corresponding continuous beam chosen (which has the same characteristics with the bridge deck but without cables).

By using all the above and by taking into account Eqs. (4.c) and (4.d), we get:

$$\left.\begin{aligned}
EI\sum_n c_n Z_n'''' &= g + p(x) - \frac{1}{b_{aj}}\sum_n c_n Z_{1n} + f_o \frac{\tan\varphi_{aj}}{b_{aj}}\Phi_a \quad \text{for} \quad 0 \le x_1 \le L_1 \\
&= g + p(x) - \frac{1}{b_{ai}}\sum_n c_n Z_{2n} - f_o \frac{\tan\varphi_{ai}}{b_{ai}}\Phi_a \quad \text{for} \quad 0 \le x_2 \le L_2/2 \\
&= g + p(x) - \frac{1}{b_{bj}}\sum_n c_n Z_{2n} - f_o \frac{\tan\varphi_{bj}}{b_{bj}}\Phi_b \quad \text{for} \quad L_2/2 \le x_2 \le L_2 \\
&= g + p(x) - \frac{1}{b_{bi}}\sum_n c_n Z_{3n} + f_o \frac{\tan\varphi_{bi}}{b_{bi}}\Phi_b \quad \text{for} \quad 0 \le x_3 \le L_3
\end{aligned}\right\} \tag{6.a}$$

where Z_{1n}, Z_{2n}, Z_{3n} are the nth shape functions of the first, second and third span.

Multiplying by Z_ρ, integrating and taking into account the orthogonality condition we get:

$$\left.\begin{aligned}
EIc_n\int_0^L Z_n''''Z_\rho dx = \int_0^L (g+p)Z_\rho dx - \int_0^{L_1}\frac{1}{b_{aj}}\sum_n c_n Z_{n1}Z_{\rho 1}dx_1 + f_o\int_0^{L_1}\frac{\tan\varphi_{aj}}{b_{aj}}\Phi_a Z_{\rho 1}dx_1 \\
-\int_0^{L_2/2}\frac{1}{b_{ai}}\sum_n c_n Z_{n2}Z_{\rho 2}dx_2 - f_o\int_0^{L_2/2}\frac{\tan\varphi_{ai}}{b_{ai}}\Phi_a Z_{\rho 2}dx_2 \\
-\int_{L_2/2}^{L_2}\frac{1}{b_{bj}}\sum_n c_n Z_{n2}Z_{\rho 2}dx_2 - f_o\int_{L_2/2}^{L_2}\frac{\tan\varphi_{bj}}{b_{bj}}\Phi_b Z_{\rho 2}dx_2 \\
-\int_0^{L_3}\frac{1}{b_{bi}}\sum_n c_n Z_{n3}Z_{\rho 3}dx_3 + f_o\int_0^{L_3}\frac{\tan\varphi_{bi}}{b_{bi}}\Phi_b Z_{\rho 3}dx_3
\end{aligned}\right\} \tag{6.b}$$

Applying the first of Eqs. (6.b) for n=1, 2, …,n, we get a linear homogeneous system, which the solution gives the unknown c_1, c_2, …,c_n.

$$\left.\begin{aligned}
&\text{where}: \quad \Phi_a = \frac{1}{1+f_o(I_{aj}+I_{ai})}\left[\int_{a_{\rho+1}}^{a_{\rho+\kappa}} \frac{\sin 2\varphi_{ai}}{2b_{ai}} \sum_n c_n Z_{n2} dx_2 - \int_{a_1}^{a_\rho} \frac{\sin 2\varphi_{aj}}{2b_{aj}} \sum_n c_n Z_{n1} dx_1\right] \\
&\qquad\quad \Phi_b = \frac{1}{1+f_o(I_{bj}+I_{bi})}\left[\int_{b_1}^{b_\rho} \frac{\sin 2\varphi_{bj}}{2b_{bj}} \sum_n c_n Z_{n2} dx_2 - \int_{b_{\kappa+1}}^{b_{\rho+\kappa}} \frac{\sin 2\varphi_{bi}}{2b_{bi}} \sum_n c_n Z_{n3} dx_3\right] \\
&\text{and}: \quad n = 1, 2, 3, \cdots\cdots, n
\end{aligned}\right\} \tag{6.c}$$

2.4 The dynamic characteristics of the bridge.

The equation of motion of a free vibrating bridge is:

$$EJ_y w''''(x,t) + c\,\dot{w}(x,t) + m\,\ddot{w}(x,t) = -q_s \tag{7.a}$$

We are searching for a solution of separate variables under the form:

$$w(x,t) = Z(x)\cdot T(t) \tag{7.b}$$

And through the well known process we get the following equations:

$$\left.Z'''' + \frac{1}{EJ_y}\left[q_c(x) + q_s(x)\right] - \lambda^4 Z = 0\,, \quad \ddot{T} + \frac{c}{m}\dot{T} + \omega^2 T = 0\,, \quad \text{where}: \ \lambda^4 = \frac{m\,\omega^2}{E\,J_y}\right\} \tag{7.c}$$

In order for us to apply the Galerkin's procedure, we set:

$$Z(x) = c_1\Psi_1(x) + c_2\Psi_2(x) + \cdots\cdots + c_n\Psi_n(x) \tag{7.d}$$

where c_i are unknown coefficients, under determination, and $\Psi_i(x)$ are functions of x arbitrarily chosen, that satisfy the boundary conditions, of the static system of bridge-deck. As such functions we choose the shape functions of the corresponding static system of beam-deck (a continuous beam or a set of three single-span beams) that has the same characteristics with the bridge-deck without cables.

Introducing Eq. (7d) into (7a), multiplying the out coming successively by $\Psi_1, \Psi_2, ..., \Psi_n$ and integrating the results from 0 to L, we obtain the following homogeneous, linear system, without second member of n equations, wit unknowns $c_1, c_2, \ldots, c_n$:

$$c_1(A_{i1} - \lambda^4 B_{i1}) + c_2(A_{i2} - \lambda^4 B_{i2}) + \cdots\cdots + c_n(A_{in} - \lambda^4 B_{in}) = 0, \quad \text{with} \quad i = 1,2,....,n \tag{7.e}$$

$$\left.\text{where:} \qquad A_{ij} = \int_0^L \left[\Psi_j'''' + \frac{1}{E\,J_y} q_s(\Psi_j)\right]\Psi_i dx \quad , \quad B_{ij} = \int_0^L \Psi_i \Psi_j dx \right\} \tag{7.f}$$

In order for the above system to have non-trivial solutions, the determinant of its coefficients must be zero:

$$\left.\left|\Gamma_{ij}\right| = 0 \quad \text{with} \quad i, j = 1, 2, \cdots, n \quad \text{and} \quad \Gamma_{ij} = A_{ij} - \lambda^4 B_{ij} \right\} \tag{7.g}$$

From Eq. (7g), we determine the values of λ and from Eq. (7c) the spectrum of the flexural eigenfrequencies ω_i. From the first (n-1) equations of the system (7e), we can find:

$$\left.\begin{aligned}&\frac{c_j}{c_1}=\frac{\begin{vmatrix}\Gamma_{12}\cdots\cdots\cdots\Gamma_{1(j-1)}\ \Gamma_{11}\ \Gamma_{1(j+1)}\ \cdots\cdots\cdots\Gamma_{1n}\\ \Gamma_{22}\cdots\cdots\cdots\Gamma_{2(j-1)}\ \Gamma_{21}\ \Gamma_{2(j+1)}\cdots\cdots\cdots\Gamma_{2n}\\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\ \Gamma_{(n-1)2}\cdots\Gamma_{(n-1)(j-1)}\ \Gamma_{(n-1)1}\ \Gamma_{(n-1)(j+1)}\cdots\Gamma_{(n-1)n}\end{vmatrix}}{\left|\Gamma_{ij}\right|}\\ &\text{with}\quad i=1,2,\cdots,(n-1)\qquad j=1,2,\cdots,n\\ &\text{and therefore :}\quad Z_n(x)=c_1\sum_{j=2}^{n}(\Psi_1+\frac{c_j}{c_1}\cdot\Psi_j)\end{aligned}\right\}\tag{7.h}$$

where $X_n(x)$ are the shape functions of the bridge with combined cable system.

2.5 Failure of cables

The following analysis concerns a cable-stayed bridge with one line of cables anchored at the center of the deck's cross-section. The problem of the failure of cables can be studied as follows.

Let us consider the bridge of figure 5a, which is at rest under the loads g (dead load) and p (live load). Thus one can determine the deformations of the deck $w_o(x)$, applying § 2.3.

Suddenly, at time t = 0 the hatched cables of Figure 5b are broken. The static system of the bridge changes to another that is like the initial one but without the failed cables. One can determine the dynamic characteristics of this new static system by applying § 2.4.

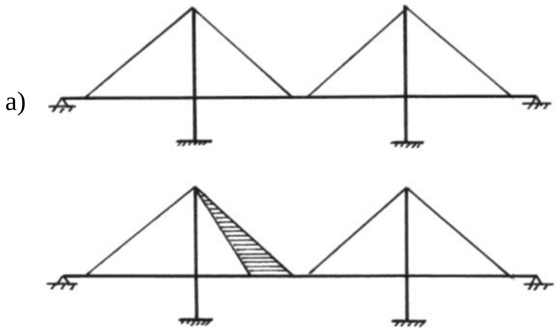


Figure 5: Initial and damaged bridge.

The equation of motion of the bridge after the failure of s cables is:

$$E\,I_y w'''' + c\dot{w} + m\ddot{w} = g + p(x)\cdot P(t) - q_s(x,w) \tag{8.a}$$

We are searching for a solution under the form:

$$w(x,t) = \sum_n Z_n(x)T_n(t) \tag{8.b}$$

where $T_n(t)$ are unknown time functions (under determination) and $Z_n(x)$ are arbitrarily chosen functions of x, which must satisfy the boundary conditions of the deck. In the present case, the shape functions of the damaged c-s-bridge are chosen as they are determined applying § 2.4.

Introducing Eq. (8b) into Eq. (8a) we get:

$$E I_y \sum_n Z_n'''' T_n + c \sum_n Z_n \dot{T}_n + m \sum_n Z_n \ddot{T}_n + q_s(x, \sum_n Z_n T_n) = g + p(x) \cdot P(t) \tag{8.c}$$

Remembering that Z_n satisfies the equation of the free motion of the wounded bridge:

$$E I_y \sum_n Z_n'''' T_n - m \sum_n \omega_n^2 Z_n T_n + q_s(x, \sum_n Z_n T_n) = 0 \tag{8.d}$$

the above Eq. (8c) becomes:

$$m \sum_n Z_n \ddot{T}_n + c \sum_n Z_n \dot{T}_n + m \sum_n \omega_n^2 Z_n T_n = g + p(x) \cdot P(t) \tag{9.a}$$

Multiplying the above by Z_k, integrating from 0 to L and remembering the orthogonality condition, we finally obtain:

$$\left.\begin{aligned} &\ddot{T}_k + \frac{c}{m}\dot{T}_k + \omega_k^2 T_k = \frac{1}{m\int_0^L Z_k^2 dx} G(t) \\ &\text{where :} \quad G(t) = \left(\int_0^L g\, Z_k\, dx + P(t) \int_0^L p(x) Z_k\, dx \right) \end{aligned}\right\} \tag{9.b}$$

The solution of the above is given by the Duhamel integral:

$$\left.\begin{aligned} &T_k(t) = \frac{1}{m\bar{\omega}_k \int_0^L Z_k^2 dx} \int_0^t e^{-\beta(t-\tau)} G(\tau) \cdot \sin[\bar{\omega}_k (t-\tau)]\, d\tau \\ &\text{where :} \quad \beta = \frac{c}{2m}, \quad \bar{\omega}_k = \sqrt{\omega_k^2 - \beta^2} \end{aligned}\right\} \tag{9.c}$$

Therefore the general solution of Eq. (7.b) is given by:

$$w(x,t) = \sum_n Z_n \left\{ e^{-\beta t} (A n \sin \bar{\omega}_n t + B_n \cos \bar{\omega}_n t) + T_n(t) \right\} \tag{9.d}$$

The constants A_n and B_n are determined from the time conditions

$w(x, t_o) = w_o(x)$ and $\dot{w}(x, t_o) = 0$ as follows:

$$\left.\begin{aligned} A_n = \frac{\beta \cdot B_n - \dot{T}_n(0)}{\bar{\omega}_n} \quad , \quad B_n = \frac{\int_0^L w_o(x) Z_n\, dx}{e^{-\beta t_o} \int_0^L Z_n^2 dx} \end{aligned}\right\} \tag{9.e}$$

3 NUMERICAL RESULTS AND DISCUSSION

In order to study the influence of the sudden failure of cables on the bridge's behavior and static adequacy, we consider a bridge with the following data: L_1=150m, L_2=350m, L_3=150m, g=7000dN/m, (m=700 gr*/m), I_b=0.50m^4, I_P=1000I_b, α_1=20m, αρ=130m, $\alpha_{\rho+1}$=30m, $\alpha_{\rho+\kappa}$=170m, β_1=180m, β_κ=320m, $\beta_{\kappa+1}$=20m, $\beta_{\kappa+\rho}$=130m, and live load p=7000dN/m. The distance between two neighboring cables is 5 m. The following five cases are studied: The non damaged bridge, a bridge under the sudden failure of 15 cables, a bridge under the sudden failure of 10 cables, a bridge under the sudden failure of 5 cables, a bridge under the sudden failure of 1 cable. Due to the restricted length of this paper the plots of the cases of the bridge under the sudden failure of 15 cables, 10 cables, 5 cables and 1 cable do not shown in this paper but they will be included in the presentation at the conference.

3.1 The non damaged bridge.

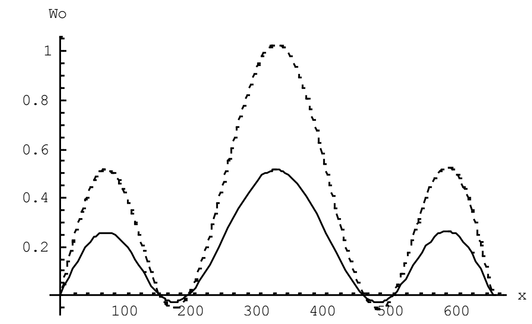


Figure 6: ___ dead load, _ _ _ dead and live loads.

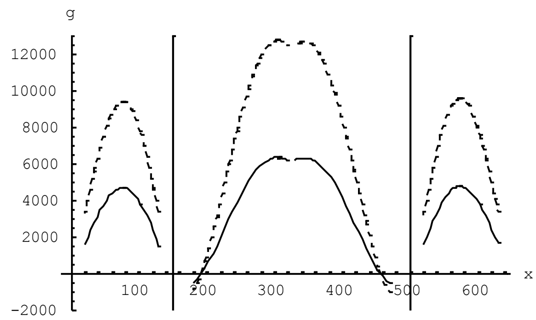
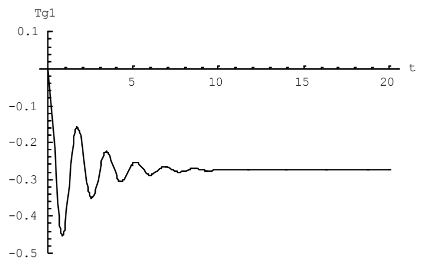


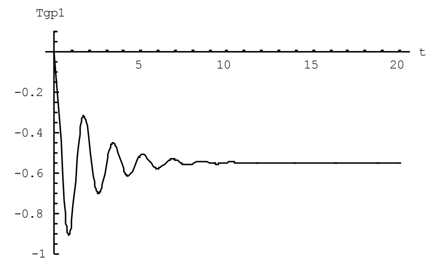
Figure 7: ___dead load, _ _ _ dead and live loads

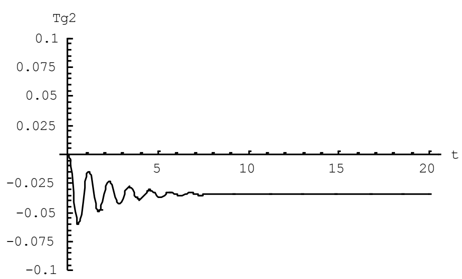
Considering the complete bridge (without failed cables) and applying the formulae of §2.3, we get the plots of Figure 6, where the deformations of the bridge are shown, and also the plots of Figure 7, where the cables' stresses are shown.

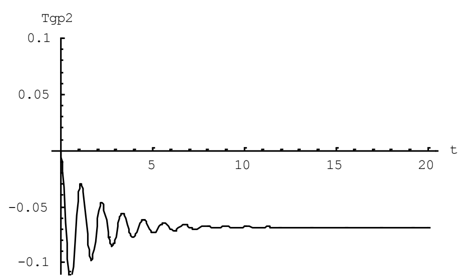
3.2 The damaged bridge

Applying the formulae of §2.5, we get the following plots concerning the three first time functions T_{g1}, T_{g2}, T_{g3} and T_{gp1}, T_{gp2}, Tgp3 for action of the dead loads and for simultaneously action of dead and live loads respectively.









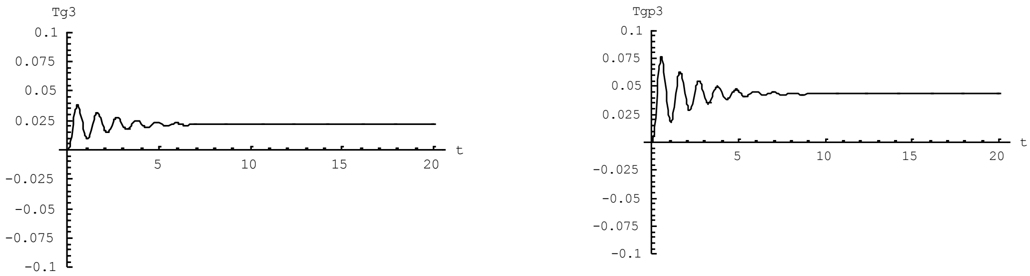


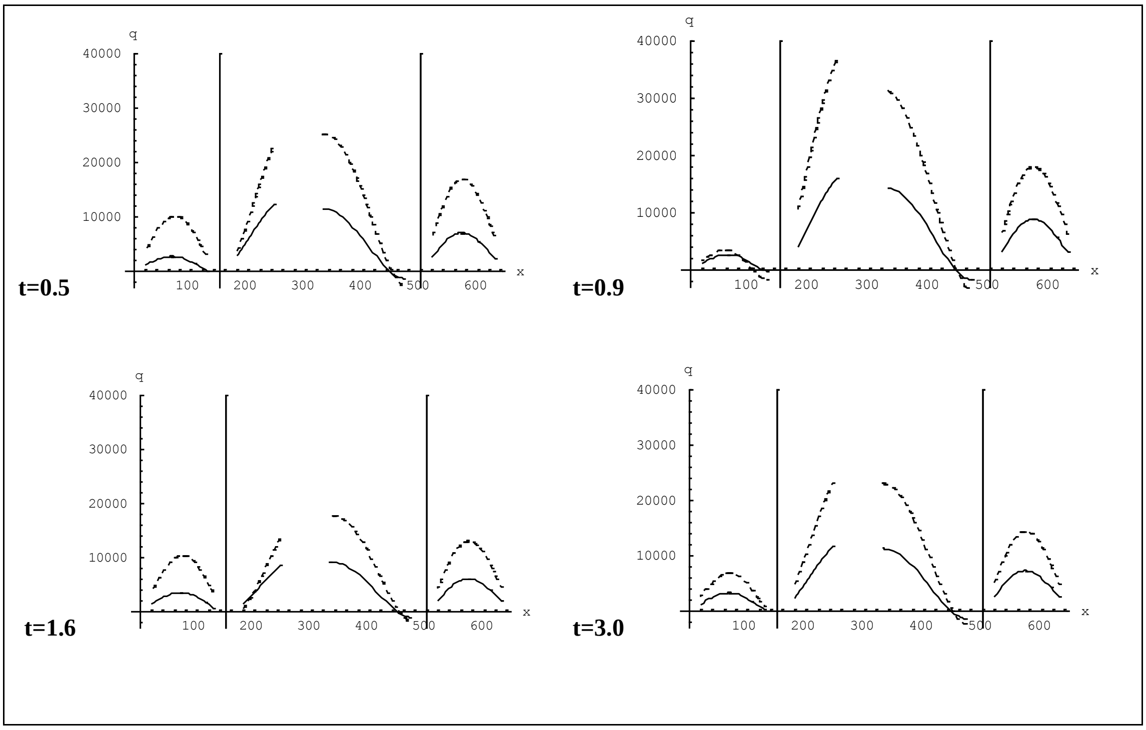
Figure 8: The time functions Ti (i = 1, 2, 3), for dead and dead+live loads

One can easily see, that after 10 seconds the bridge becomes at rest, while the maximum excitation happens at t=0.9sec after the sudden failure of cables.

3.2.1 A more detailed observation of the cables' stresses

Let us see now the cables' stresses at different instants. Studying the behaviour of the bridge in connection with time, we get the following table 1, showing the cables' stresses time succession.

We see the passage of the stresses of some cables from their maximum (at t = 0.9 sec, immediately after fracture) to negative stresses (i.e. unstressed cables).



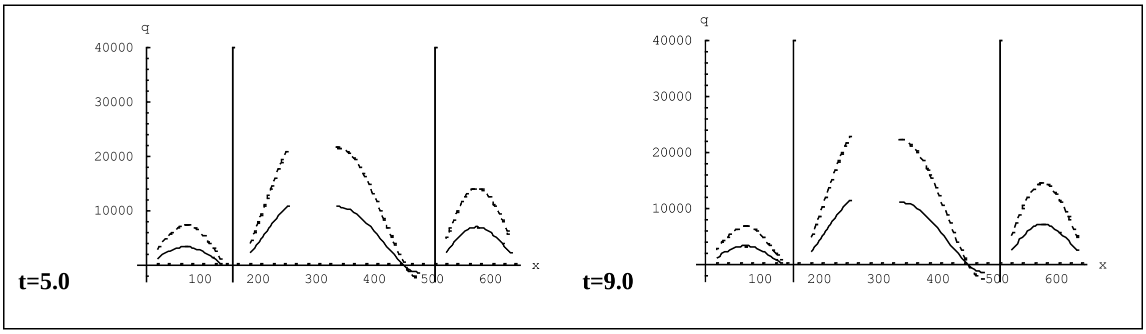


Table 1: Cables' stresses time succesion

4 CONCLUSIONS

A simple approach for studying the response of C-S-Bridges, due to sudden failure of a cable or cables is exhibited. The results presented herein have been obtained by closed form analytical solutions. On the basis of the representative C-S-Bridge models analyzed here, the following conclusions can be drawn:

- We must dissociate the case of a sudden fracture of one or more cables, caused by an accident or an unexpected incident, from the case of a programmed (or planed) replacement of some cables. In the first case, even if only one cable is failed, the developed distresses are great, especially for a loaded bridge. In the second case (bridge in rest), we can replace a great number of cables (mainly for an unloaded bridge).
- The sudden failure of cables, induces the bridge to unexpected violent and unforeseen oscillations of great amplitude. Therefore it is obvious that none of the codes can confront such an incident. The consequences of a violent cable failure are so intense, that unexpected phenomena appear as for example instantaneously unstressed cables.
- The deformations of the deck can be greater from 1.05 to 2.5 times than the ones of the same bridge in rest while the cables' stresses can be greater from 1.1 to 3.3 times respectively.
- The proposed by SETRA and PTI recommendations dynamic amplification factor (with maximum value equal to 2.0) is sufficient and satisfies the sudden failure up to 5 cables. But given that such a failure of more than one or two cables is produced by an accident or explosion, and that we have additional distress produced by the accident or explosion it self, it is obvious that the above mentioned factor must be significantly greater.

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