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Highlights

- Wastes on Building Procurement
- Surface and Internal Solitary Waves
- Evaluation of Seismic Performance
- Causes of Delays in Road Construction

Discovering Thoughts, Inventing Future

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A Numerical Solution for the Coexisting Field of Surface and Internal Solitary Waves

By Taro Kakinuma & Kei Yamashita
Kagoshima University

Abstract- The numerical solutions for the coexisting fields of surface and internal solitary waves have been obtained, where the set of nonlinear equations based on the variational principle for steady waves are solved using the Newton- Raphson method. The relative phase velocity of surface-mode solitary waves is smaller in the coexisting fields of surface and internal solitary waves than in the cases without the coexistence of internal waves. The relative phase velocity of internal-mode solitary waves is also smaller in the coexisting fields of surface and internal solitary waves than in the cases without surface waves. The interfacial position of an internalmode internal solitary wave in a coexisting field of surface and internal waves can exceed the critical level determined in the corresponding case without a surface wave. The wave height ratio between internal-mode surface and internal solitary waves is smaller than the corresponding linear shallow water wave solution, and the difference increases, as the relative wave height of internal-mode internal solitary waves is increased.

Keywords: solitary wave, internal wave, free surface, nonlinear wave equation, numerical solution.

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A Numerical Solution for the Coexisting Field of Surface and Internal Solitary Waves

Taro Kakinuma [α] & Kei Yamashita [σ]

Abstract- The numerical solutions for the coexisting fields of surface and internal solitary waves have been obtained, where the set of nonlinear equations based on the variational principle for steady waves are solved using the Newton-Raphson method. The relative phase velocity of surface-mode solitary waves is smaller in the coexisting fields of surface and internal solitary waves than in the cases without the coexistence of internal waves. The relative phase velocity of internal-mode solitary waves is also smaller in the coexisting fields of surface and internal solitary waves than in the cases without surface waves. The interfacial position of an internal-mode internal solitary wave in a coexisting field of surface and internal waves can exceed the critical level determined in the corresponding case without a surface wave. The wave height ratio between internal-mode surface and internal solitary waves is smaller than the corresponding linear shallow water wave solution, and the difference increases, as the relative wave height of internal-mode internal solitary waves is increased.

Keywords: solitary wave, internal wave, free surface, nonlinear wave equation, numerical solution.

I. Introduction

Surface and internal waves coexist in the ocean with stratification development. The behaviors of waves in such coexisting fields of surface and internal waves show more complicated characteristics than those which exist individually. For instance, the traveling time for a distant tsunami is delayed due to the influence of density stratification in the ocean, according to the theoretical analyses for linear waves[1), 2)]. Fructus and Grue[3)] used a pressure field for two-layer fluids sandwiched by two fixed horizontal plates, to obtain the surface waves caused by large-amplitude internal waves. A coexisting field of surface and internal waves can be established even in nearshore zones, where surface long waves have great influence on sediment motion and coastal structures as an external force, and conversely, internal waves may greatly affect the coastal environment through water salinity and temperature. Surface and internal waves, however, have often been studied individually: especially, the nonlinear characteristics of surface and internal waves have been investigated independently by e.g. Longuet-Higgins and Fenton[4)] and Choi and Camassa[5)]. In also the research by Fructus and Grue[3)] mentioned above, the interaction between surface and internal waves has not been considered.

In the present study, solitary wave solutions for coexistence fields of surface and internal waves have been numerically calculated using the set of nonlinear wave equations based on the variational principle[6)] for two-layer fluids with a free water surface, to examine the characteristics of surface and internal solitary waves, where the phases of both the steady surface and internal solitary waves are assumed to be the same, with a surface mode or an internal mode.

II. Fundamental Equations

The motion in two-layer inviscid and incompressible fluids is assumed to be irrotational. The upper and lower layers are called the first and second layers, respectively, and the fluids in each layer do not mix even in motion. The velocity potential ϕ_i in the i-th layer (i = 1 or 2) is expanded into the power series of vertical position z, in the manner similar to that for the derivation process of nonlinear surface wave equations[7)], as

$$\phi_i(\boldsymbol{x},z,t)=\sum_{\alpha_i=0}^{N_i-1}\left[f_{i,\alpha_i}(\boldsymbol{x},t)\cdot z^{\alpha_i}\right], \tag{1}$$

where N_i is the number of terms and f_{i,α_i} is the weightings of the power series.

By applying the variational principle, the nonlinear surface/internal wave equations[6)] are obtained as follows:

The upper and 1st layer

$$\zeta^{\alpha_1}\frac{\partial\zeta}{\partial t}-\eta^{\alpha_1}\frac{\partial\eta}{\partial t}+\frac{1}{\alpha_1+\beta_1+1}\nabla\left[\left(\zeta^{\alpha_1+\beta_1+1}-\eta^{\alpha_1+\beta_1+1}\right)\nabla f_{1,\beta_1}\right]-\frac{\alpha_1\beta_1}{\alpha_1+\beta_1-1}\left(\zeta^{\alpha_1+\beta_1-1}-\eta^{\alpha_1+\beta_1-1}\right)f_{1,\beta_1}=0, \tag{2}$$

$$\zeta^{\beta_1}\frac{\partial f_{1,\beta_1}}{\partial t}+\frac{1}{2}\zeta^{\beta_1+\gamma_1}\nabla f_{1,\beta_1}\nabla f_{1,\gamma_1}+\frac{1}{2}\beta_1\gamma_1\zeta^{\beta_1+\gamma_1-2}f_{1,\beta_1}f_{1,\gamma_1}+g\zeta=0, \tag{3}$$

Author α: Graduate School of Science and Engineering, Kagoshima University, 1-21-40 Korimoto, Kagoshima, Kagoshima 890-0065, Japan. e-mail: taro@oce.kagoshima-u.ac.jp
Author σ: International Research Institute of Disaster Science, Tohoku University, 468-1 Aramaki Aza-Aoba, Aoba-ku, Sendai, Miyagi 980-8572, Japan. e-mail: kyamashita@irides.tohoku.ac.jp

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$$\eta^{\beta_1}\frac{\partial f_{1,\beta_1}}{\partial t}+\frac{1}{2}\eta^{\beta_1+\gamma_1}\nabla f_{1,\beta_1}\nabla f_{1,\gamma_1}+\frac{1}{2}\beta_1\gamma_1\eta^{\beta_1+\gamma_1-2}f_{1,\beta_1}f_{1,\gamma_1}+g\eta+\frac{p}{\rho_1}=0, \tag{4}$$

The lower and 2nd layer

$$\eta^{\alpha_2}\frac{\partial\eta}{\partial t}+\frac{1}{\alpha_2+\beta_2+1}\nabla\left[\left(\eta^{\alpha_2+\beta_2+1}-b^{\alpha_2+\beta_2+1}\right)\nabla f_{2,\beta_2}\right]-\frac{\alpha_2\beta_2}{\alpha_2+\beta_2-1}\left(\eta^{\alpha_2+\beta_2-1}-b^{\alpha_2+\beta_2-1}\right)f_{2,\beta_2}=0, \tag{5}$$

$$\eta^{\beta_2}\frac{\partial f_{2,\beta_2}}{\partial t}+\frac{1}{2}\eta^{\beta_2+\gamma_2}\nabla f_{2,\beta_2}\nabla f_{2,\gamma_2}+\frac{1}{2}\beta_2\gamma_2\eta^{\beta_2+\gamma_2-2}f_{2,\beta_2}f_{2,\gamma_2}+g\eta+\frac{1}{\rho_2}\left[p+(\rho_2-\rho_1)gh_1\right]=0, \tag{6}$$

where ζ, η, b, p, h_1, and ρ_i are the water surface displacement, interface displacement, seabed position, pressure at the interface, the upper-layer thickness in still water, and fluid density of the i-th layer, respectively. The fluid density ρ_i is constant in each layer. The horizontal partial differential operator ∇ is $(\partial/\partial x, \partial/\partial y)$, and g is the gravitational acceleration, i.e., $g = 9.8$ m/s^2.

It should be noted that the sum rule of product is used for the subscripts α_i, β_i, and γ_i: for example, β_1 in the first term on the left-hand side of Eq. (3) is the power of ζ.

From Eqs. (4) and (6), p is eliminated to obtain the following equation:

$$\eta^{\beta_2}\frac{\partial f_{2,\beta_2}}{\partial t}+\frac{1}{2}\eta^{\beta_2+\gamma_2}\nabla f_{2,\beta_2}\nabla f_{2,\gamma_2}+\frac{1}{2}\beta_2\gamma_2\eta^{\beta_2+\gamma_2-2}f_{2,\beta_2}f_{2,\gamma_2}+\left(1-\frac{\rho_1}{\rho_2}\right)g(\eta+h_1)$$
$$-\frac{\rho_1}{\rho_2}\left(\eta^{\beta_1}\frac{\partial f_{1,\beta_1}}{\partial t}+\frac{1}{2}\eta^{\beta_1+\gamma_1}\nabla f_{1,\beta_1}\nabla f_{1,\gamma_1}+\frac{1}{2}\beta_1\gamma_1\eta^{\beta_1+\gamma_1-2}f_{1,\beta_1}f_{1,\gamma_1}\right)=0. \tag{7}$$

In this study, we focus on solitary waves, such that the number of terms for the expanded velocity potential expressed by Eq. (1) is three for both upper and lower layers, i.e., $N_1 = N_2 = N = 3$, based on the accuracy verification[8)] for the surface and internal solitary waves obtained using the fundamental equations.

III. Calculation Method for Steady Wave Solutions in a Coexisting Field of Surface and Internal Solitary Waves

a) Determinant in the Newton-Raphson method

For the propagation of nonlinear surface/internal waves, the fundamental differential equations, i.e., Eqs. (2), (3), (5), and (7), are transformed to finite difference equations, which are solved using an implicit scheme[9)]. In the present study, numerical solutions for surface/internal solitary waves are obtained using the method introduced by Yamashita and Kakinuma[8)], where the Newton-Raphson method is applied to solve the fundamental equations for steady waves in a coexisting fields of surface and internal waves. We substitute the advection equation $\partial F/\partial t = -C\, \partial F/\partial x$ into the time derivative terms of Eqs. (2), (3), (5), and (7), and then solve the resulting nonlinear wave equations for steady waves traveling in the direction of the x-axis, where C is the phase velocity of the waves, and the physical quantity F is the water surface displacement ζ, the interface displacement η, and the weightings of the expanded velocity potential $f_{i,\alpha}$. In this method, an arbitrary phase velocity C is given, and these unknown physical quantities for a steady wave with phase velocity C are evaluated using the Newton-Raphson method. Note that in the resulting equations for steady waves, the physical quantities F are functions of only x, for the time derivative terms are eliminated.

For the discretization in the Newton-Raphson method, the second-order central finite difference is used for spatial differentiation. The computational domain is the region of $1 \le m \le M$, where m is grid point number. The grid points of $m = 0$ and $m = M + 1$ are virtual grid points for the central finite difference at the lateral boundaries.

The method to solve the determinant $J\Delta = D$, which represents the simultaneous difference equations obtained by the discretization above, is the Gaussian elimination method, with partial pivots of high computational stability, where $J = J(m)$ ($m = (1, 2, \cdots, M)$) is the Jacobian matrix, and $\Delta = \Delta(m)$ is a column vector composed of the difference ΔF between the numerical solution F at the k th and that at the $(k + 1)$ th iterative calculations for convergence.

The number of elements of the Jacobian matrix J is $\{(2 + 2N) M\}^2$. For example, if the number of grids in the computational domain is 2,500, the total number of elements is about 400 million, such that it is not efficient to store the Jacobian matrix J in one array, from the viewpoint of memory capacity. Therefore, considering that the Jacobian matrix J is a band matrix, we secure only both the elements required to the pivot operation and those of the Jacobian matrix J corresponding to $\Delta(m) = (\Delta f_{1,\alpha}, \Delta\zeta, \Delta\eta, \Delta f_{2,\alpha})_m$ for one computational grid point, such that the Jacobian matrix J is composed of $(2 + 2N) \times 4(2 + 2N) \times M$.

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Consequently, the number of elements has been reduced to around 640,000, and the calculation efficiency could be improved significantly.

b) Initial values in the Newton-Raphson method

The initial values in the Newton-Raphson method are the surface and interface profiles, as well as the velocity potential, obtained through the KdV theory for small amplitude solitary waves. In two-layer fluids, there are two types of solitary waves with different restoring forces: solitary waves with a surface-wave mode due to gravity, as sketched in Fig. 1, and solitary waves with an internal-wave mode owing to the effective gravity between the two layers, as illustrated in Fig. 2. For the former, the initial values in the Newton-Raphson method are the KdV solutions for a one-layer fluid, and for the latter, those are the KdV solutions for two-layer fluids, the upper surface of which contacts with a fixed horizontal plate.

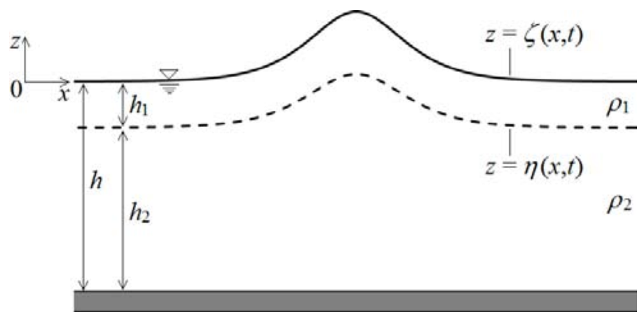

Fig. 1: Schematic for surface-mode surface and internal solitary waves in two-layer fluids with free water surface.

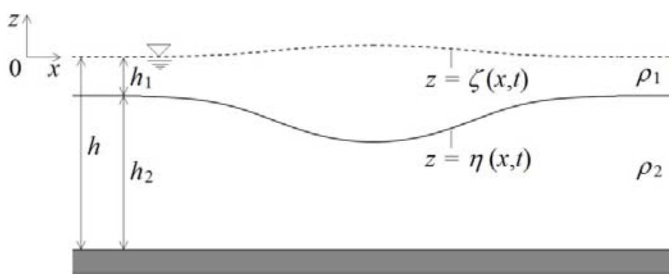

Fig. 2: Schematic for internal-mode surface and internal solitary waves in two-layer fluids with free water surface.

c) Lateral boundary conditions for approximating solitary waves in the finite domain

Solitary waves have the property that the horizontal gradient dF/dx of the physical quantity asymptotically approaches zero at a distance in the horizontal direction. In the numerical calculation, however, the target domain is a finite region, such that the property should be described using boundary conditions. First, as a boundary condition of the calculation using the central finite difference, we assumed $dF/dx = 0$ for the physical quantities F at the virtual grid points, i.e., $m = 0$ and $m = M + 1$, and then the calculation diverged immediately. Second, although we extrapolated the physical quantities F at the virtual grid points $m = 0$ and $M + 1$ using the first- or second-order approximation, the calculation also diverged. These calculation results indicate that the water surface displacement ζ near the boundaries oscillates without asymptotically approaching zero toward the boundary, which means that in order to obtain stable solutions, it is necessary to suppress such oscillation and express that dF/dx approaches zero toward the boundaries. Finally, we adopted $F_0 = F_1$ and $F_{M+1} = F_M$, which means that the gradient of physical quantities in the virtual regions adjacent to the boundaries is assumed to be zero, although it does not mean $dF/dx = 0$ at the boundaries. For example, dF/dx at the boundary $m = 1$ is expressed as $(F_2 - F_1)/\ 2\Delta x$, which has the same sign as dF/dx at the position $m \simeq 1.5$, and the absolute value is 1/2 of dF/dx at the position $m \simeq 1.5$, such that the oscillation due to sign reversal around the boundaries is suppressed, and the property of solitary waves, where dF/dx approaches zero toward the boundary, is approximately expressed.

IV. Surface-Mode Solitary Waves

The illustration in Fig. 1 is our schematic for surface and internal solitary waves with a surface-wave mode, where the still water depth $h = h_1 + h_2$ is uniform, and the thickness of the upper layer h_1 is 0.2h in still water. By applying the final method described above, we obtain numerical solutions for surface-mode solitary waves, where the phases of both surface-mode surface and internal solitary waves are assumed to be the same as shown in Fig. 1.

The density ratio of the lower and upper layers, ρ_2/ρ_1, is 1.02, which is close to the density ratio of seawater and freshwater. The total length of the calculation domain, L, is 100.0h, and the grid width in the x direction, Δx, is 0.05h.

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Shown in Fig. 3 are the numerical results for the water surface profiles of the surface-mode surface solitary waves, where the horizontal and vertical axes indicate horizontal distance from the position of the wave-profile peak and the ratio of surface displacement from the still water level to still water depth h. The ratio of the wave height of the surface solitary waves to still water depth, a_s/h, is 0.1, 0.3, and 0.5. Comparing the water surface profiles of the surface solitary waves for the one-layer fluid indicated by the black solid lines and those for the two-layer fluids drawn with the red broken lines, a significant difference is not observed between the two, although the latter is slightly sharpened.

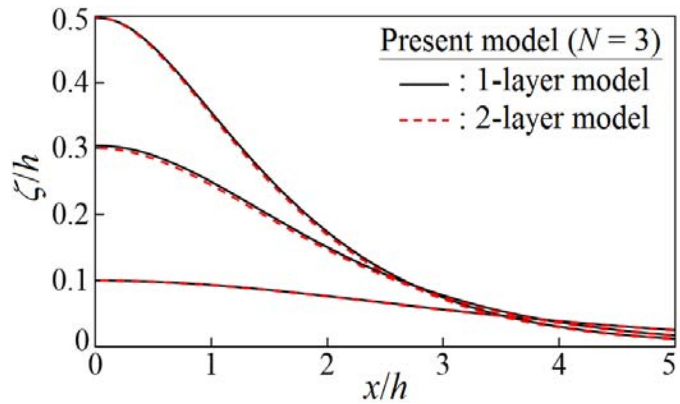

Fig. 3: Surface profiles for the surface-mode surface solitary waves, where the ratio of wave height to still water depth a_s/h = 0.1, 0.3, and 0.5; h_2/h_1 = 4.0 and ρ_2/ρ_1 = 1.02.

Figure 4 shows the relationship between the relative representative wavelength of surface-mode surface solitary waves, λ_s/h, and the ratio of wave height to still water depth, a_s/h, where the red solid line shows the numerical solution for the two-layer fluids, and the black solid and broken lines show the numerical solution and the KdV solution for the one-layer fluid, respectively. The representative wavelength λ_s of surface solitary waves is defined by

$$\lambda_s = \int_{-L/2}^{L/2} \zeta \, dx \Big/ a_s \, . \tag{8}$$

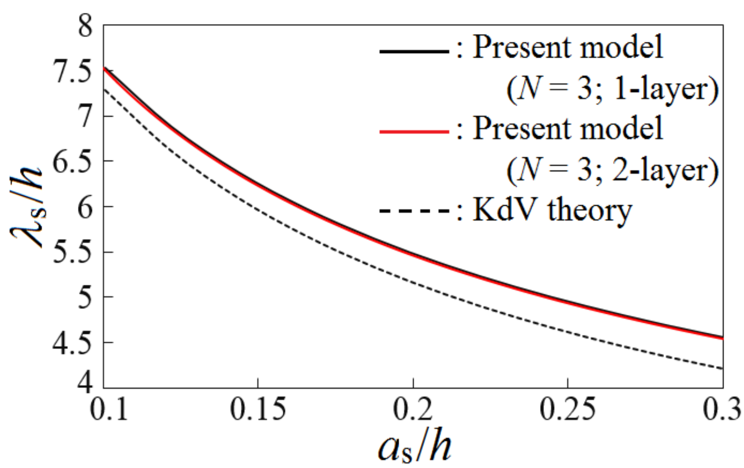

Fig. 4: Relationship between the relative representative wavelength of surface-mode surface solitary waves, λ_s/h, and the ratio of wave height to still water depth, a_s/h, where λ_s is defined by Eq. (8); h_2/h_1 = 4.0 and ρ_2/ρ_1 = 1.02.

Fig. 4 indicates that the relative representative wavelength decreases, as the ratio of wave height to still water depth, a_s/h, is increased. Although the representative wavelength for the two-layer fluids is slightly shorter than that for the one-layer fluid, there is almost no difference between the two. The representative wavelength from the KdV theory for the one-layer fluid is shorter than those through the numerical calculation for the one-layer fluid and the two-layer fluids, for the wavelength by the KdV theory decreases as the wave height is increased, satisfying the assumption that $O(a_s/h) = O((h/\lambda_s)^2)$. Conversely, in the derivation process of the set of fundamental equations[6], no assumptions are made regarding both the ratio of wave height to water depth and the ratio of water depth to wavelength, when the number of the expansion terms for velocity potential, N, is infinity.

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Figure 5 shows the relationship between the relative phase velocity $C/C_{s,0}$ and the ratio of wave height to still water depth, a_s/h, for the surface-mode surface solitary waves, where $C_{s,0} = \sqrt{gh}$ is the phase velocity of linear shallow water waves for a one-layer fluid. In Fig. 5, the red solid line shows the numerical solution for the two-layer fluids, and the black solid and broken lines indicate the numerical solution and the KdV solution, respectively, for the one-layer fluid. The relative phase velocity $C/C_{s,0}$ through the numerical calculation is smaller than the KdV solution, and the numerical solution of $C/C_{s,0}$ is smaller for the two-layer fluids than for the one-layer fluid. The difference $\Delta(C/C_{s,0})$ between the numerical solution for the one-layer fluid and that for the two-layer fluids is 2.0×10^{-3}, 1.8×10^{-3}, 1.4×10^{-3}, and 6.0×10^{-5}, when $a_s/h = 0.1$, 0.3, 0.5, and 0.6, respectively, where $\Delta(C/C_{s,0})$ decreases as a_s/h is increased.

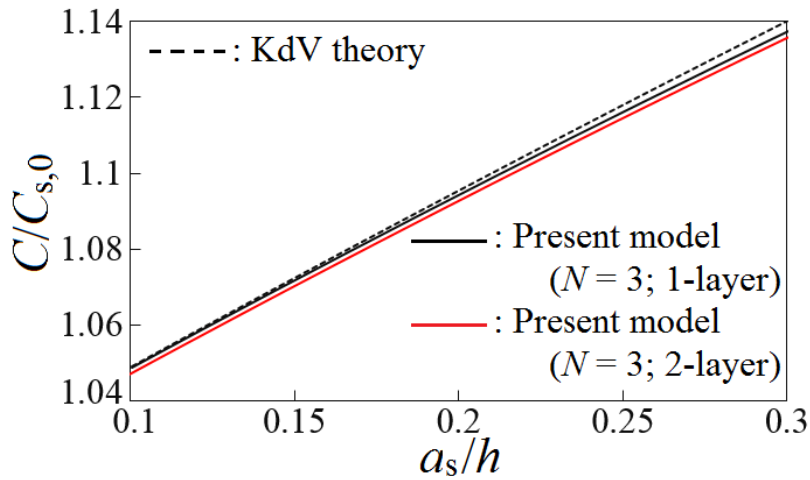

Fig. 5: Relationship between the relative phase velocity $C/C_{s,0}$ and the ratio of wave height to still water depth, a_s/h, for the surface-mode surface solitary wave, where $C_{s,0} = \sqrt{gh}$ is the phase velocity of linear shallow water waves for a one-layer fluid; $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.02$.

Shown in Fig. 6 is the ratio of the wave height a_i of surface-mode internal solitary waves to the wave height a_s of surface-mode surface solitary waves, for the two-layer fluids. Although the numerical solution of a_i/a_s is close to 0.8, which is the value through the linear theoretical solution for small-amplitude surface solitary waves, the difference between the value of a_i/a_s through the numerical calculation and that from the linear theory increases, a_s/h is increased.

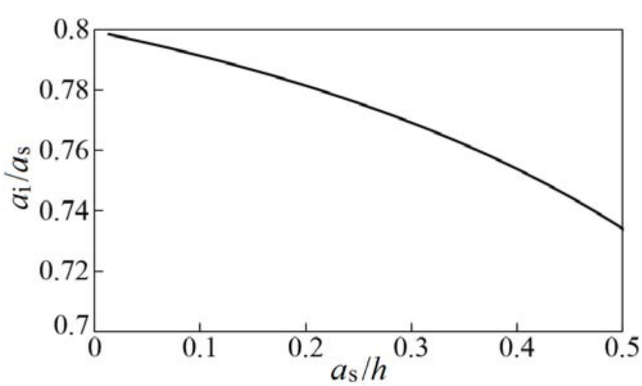

Fig. 6: Relationship between the wave height ratio a_i/a_s and the ratio of wave height to still water depth, a_s/h, where a_i and a_s are the wave height of surface-mode internal and surface solitary waves, respectively; $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.02$.

In the following cases, the density ratio of lower and upper layers, ρ_2/ρ_1, is 1.20. In the numerical calculation, the total length of the calculation domain, L, is $50.0h$, and the grid width in the x direction, Δx, is $0.02h$. Figure 7 shows the numerical results for the water surface profiles of surface-mode surface solitary waves, where the ratio of the wave height of surface solitary waves to still water depth, a_s/h, is 0.5. The distance between the front and back surfaces of the wave profile at each height of the surface-mode surface solitary wave is shorter in the coexisting field of surface and internal waves than in the case without internal waves.

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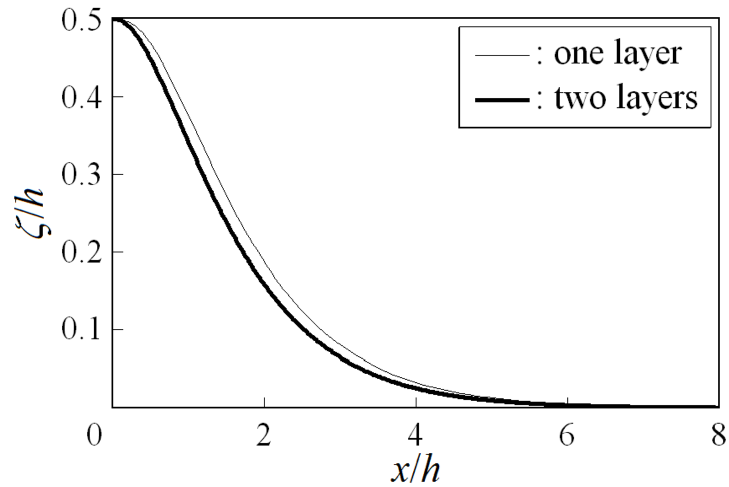

Fig. 7: Surface profiles of surface-mode surface solitary waves, where the ratio of the wave height of surface solitary waves to still water depth, a_s/h, is 0.5; $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.20$.

Figure 8 indicates the relationship between the relative representative wavelength of surface-mode surface solitary waves, λ_s/h, and the ratio of their wave height to water depth, a_s/h, where the thick and thin lines show the numerical solutions for the two-layer fluids and for the one-layer fluid, respectively. The representative wavelength λ_s is defined by Eq. (8). The relative representative wavelength decreases, as the ratio of wave height to still water depth, a_s/h, is increased, as in the case shown in Fig. 4.

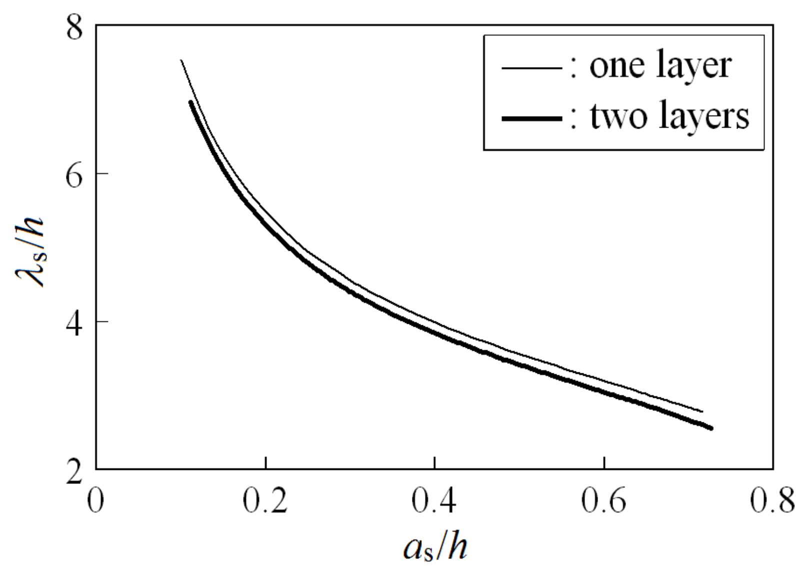

Fig. 8: Relationship between the relative representative wavelength of surface-mode surface solitary waves, λ_s/h, and the ratio of their wave height to water depth, a_s/h, where λ_s is defined by Eq. (8); $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.20$.

Figure 9 shows the relationship between the relative phase velocity $C/C_{s,0}$ and the ratio of wave height to water depth, a_s/h, for surface-mode surface solitary waves, where $C_{s,0} = \sqrt{gh}$ is the phase velocity of linear shallow water waves for a one-layer fluid. The numerical solution for relative phase velocity $C/C_{s,0}$ is smaller for the two-layer fluids than for the one-layer fluid, which is the same as in the case shown in Fig. 5.

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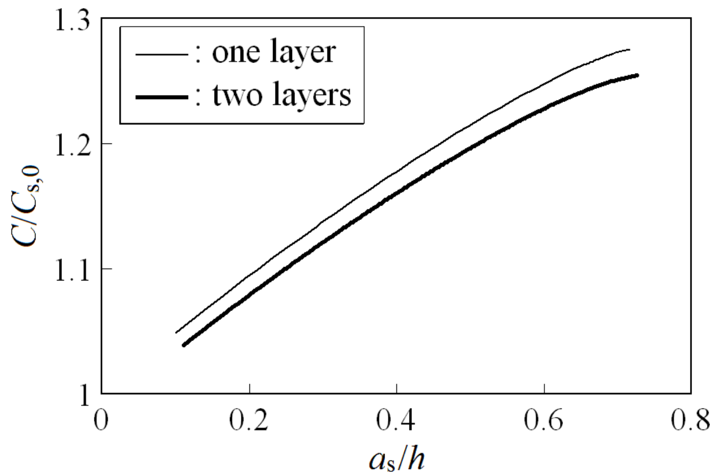

Fig. 9: Relationship between the relative phase velocity $C/C_{s,0}$ and the ratio of wave height to water depth, a_s/h, for surface-mode surface solitary waves, where $C_{s,0} = \sqrt{gh}$ is the phase velocity of linear shallow water waves for a one-layer fluid; $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.20$.

Shown in Fig. 10 is the ratio of the wave height a_i of surface-mode internal solitary waves to the wave height a_s of surface-mode surface solitary waves, for the two-layer fluids. The surface-mode wave height ratio a_i/a_s decreases, as the relative wave height of surface-mode surface solitary waves, a_s/h, is increased, as in the case shown in Fig. 6.

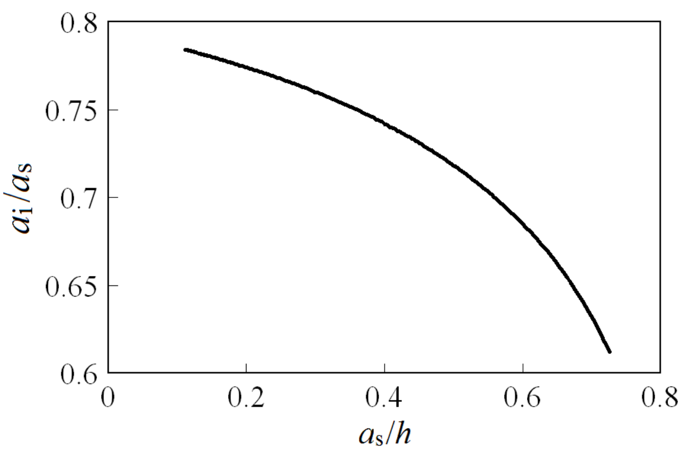

Fig. 10: Relationship between the wave height ratio a_i/a_s and the ratio of wave height to still water depth, a_s/h, where a_i and a_s are the wave height of surface-mode internal and surface solitary waves, respectively; $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.20$.

V. Internal-Mode Solitary Waves

Illustrated in Fig. 2 are internal-mode surface and internal solitary waves, where the still water depth h is uniform, and the thickness of the upper layer h_1 is $0.2h$ in still water. By applying the same method, the numerical solutions for internal-mode solitary waves are obtained, where the phases of both internal-mode surface and internal solitary waves are assumed to be the same as shown in Fig. 2. The total length of the calculation domain, L, is $25.0h$, and the grid width in the x direction, Δx, is $0.005h$. First, the density ratio of the lower and upper layers, ρ_2/ρ_1, is 1.02.

The numerical solutions for the interface profiles of internal-mode internal solitary waves are shown in Fig. 11. The red lines indicate the interface profiles for the coexisting field of both surface and internal solitary waves, where the ratio of wave height to upper-layer thickness in still water, a_i/h_1, is 0.15, 0.5, and 1.0, as well as 1.493, which is the maximum value obtained by numerical calculation. On the other hand, the black line shows the numerical solution for the interface profile of the internal solitary wave with the obtained maximum wave height, where the upper surface is in contact with a fixed horizontal plate. In the absence of a free water surface, the downward convex interface of stable internal waves cannot appear below the height of $(z_c + h_1)/h_1 = -1.488$, which is called the critical level[10)]. Figure 11, however, indicates that $(\eta_{min} + h_1)/h_1 = -1.493$, such that the interfacial minimum position η_{min} can exceed the critical level, when the free water surface coexists.

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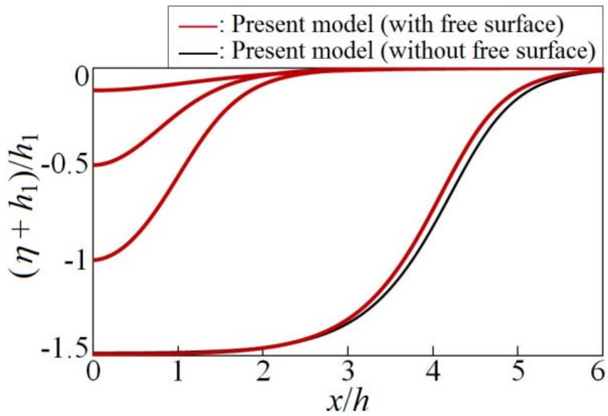

Fig. 11: Interface profiles of internal-mode internal solitary waves, where $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.02$. The red lines indicate the interface profiles for the coexisting fields of both surface and internal solitary waves, where the ratio of wave height to upper-layer thickness in still water, a_i/h_1, is 0.15, 0.5, and 1.0, as well as 1.493, which is the maximum value obtained by numerical calculation. The black line shows the numerical solution for the interface profile of the internal solitary wave with the obtained maximum wave height, where the upper surface is in contact with a fixed horizontal plate.

Figure 12 shows the relative representative wavelength λ_i/h_1 for internal-mode internal solitary waves, where the red solid line shows the numerical solution for the coexisting field of surface and internal waves, and the black solid and broken lines show the numerical solution and the KdV solution, respectively, when the upper surface is in contact with the fixed horizontal plate. The representative wavelength λ_i is defined by

$$\lambda_i = \int_{-L/2}^{L/2} |\eta + h_1| dx \Big/ a_i \, . \tag{9}$$

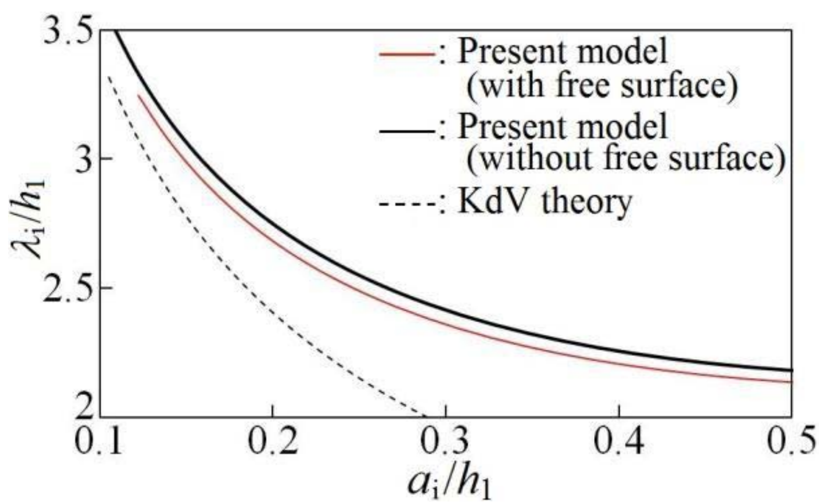

Fig. 12: Relationship between the relative representative wavelength λ_i/h_1 and the ratio of wave height to upper layer thickness in still water, a_i/h_1, for internal-mode internal solitary waves, where the representative wavelength λ_i is defined by Eq. (9); $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.02$.

As shown in Fig. 12, the numerical solution for the representative wavelength of internal-mode solitary waves in the coexistence field of surface and internal waves is shorter than that for the case without the coexistence of surface waves. These numerical solutions are larger than the corresponding KdV solution, which is similar to surface-mode surface solitary waves shown in Fig. 4.

Figure 13 shows the relative phase velocity $C_i/C_{i,0}$ of internal-mode solitary waves, where $C_{i,0} = \sqrt{(\rho_2-\rho_1)gh_1h_2/(\rho_2h_1+\rho_1h_2)}$ is the phase velocity of linear internal shallow water waves without the coexistence of surface waves. As indicated in Fig. 13, the relative phase velocity $C_i/C_{i,0}$ decreases in the coexistence field of surface and internal waves than in the case without the coexistence of surface waves, where the difference between the two decreases as a_i/h_1 is increased, as for the case of surface-mode solitary waves shown in Fig. 5.

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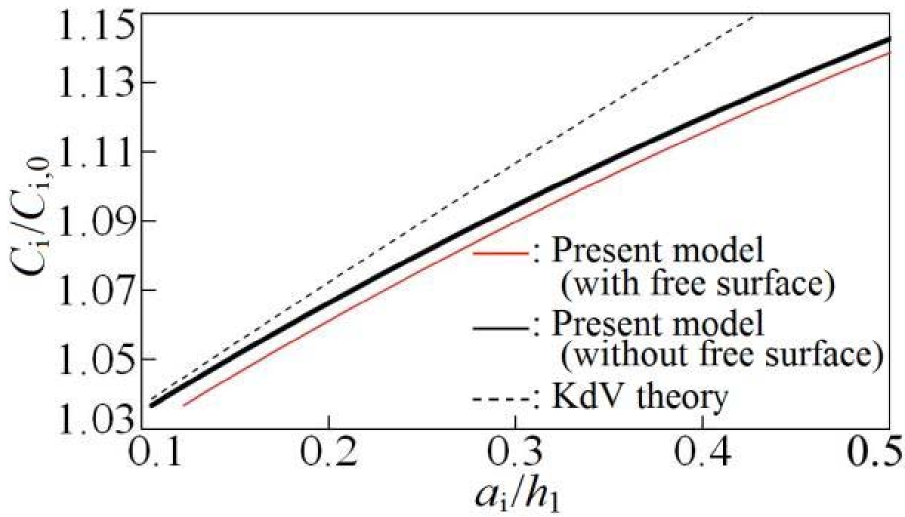

Fig. 13: Relationship between the relative phase velocity $C_i/C_{i,0}$ and the ratio of wave height to upper-layer thickness in still water, a_i/h_1, for internal-mode internal solitary waves, where $C_{i,0}$ is the phase velocity of linear internal shallow water waves without the coexistence of surface waves; $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.02$.

Shown in Fig. 14 is the ratio of wave height of internal-mode surface solitary waves to that of internal-mode internal solitary waves, a_s/a_i. The wave height ratio a_s/a_i decreases, as the ratio a_i/h_1 is increased. Conversely, the wave height ratio a_s/a_i from the linear shallow water wave theory for the coexisting field of surface and internal waves does not depend on the ratio a_i/h_1, for $a_s/a_i = (1- \rho_1/\rho_2)\, h_2/h = 0.016$.

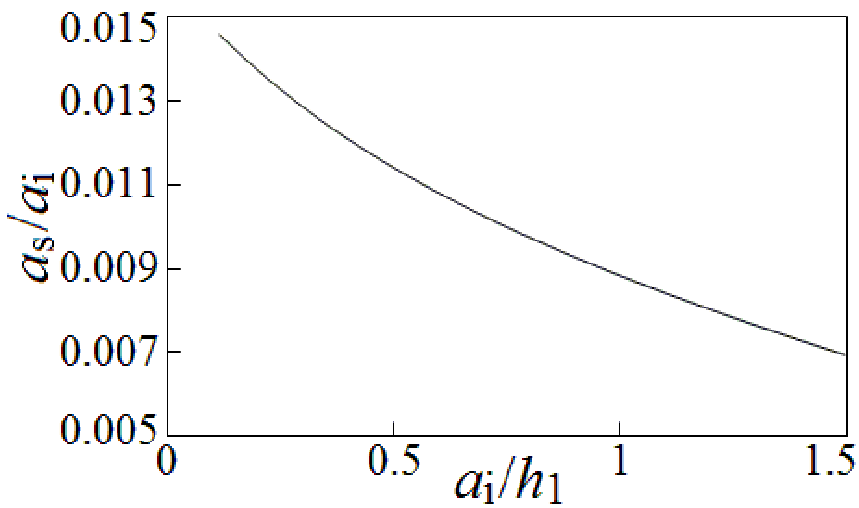

Fig. 14: Relationship between the wave height ratio a_s/a_i and the ratio of wave height to the upper layer thickness in still water, a_i/h_1, where a_s and a_i are the wave height of internal-mode surface and internal solitary waves, respectively; $h_2/h_1 = 4.0$ and $\rho_2/\rho_1 = 1.02$.

Second, we compare the numerical solutions for two cases, where the density ratio of the lower and upper layers, ρ_2/ρ_1, is 1.02 and 1.20. Figure 15 shows the relative representative wavelength λ_i/h_1 for internal-mode internal solitary waves, where λ_i is defined by Eq. (9). As shown in Fig. 15, although the representative wavelength λ_i of internal-mode internal solitary waves in the coexisting field of surface and internal waves is larger in the case where $\rho_2/\rho_1 = 1.02$ than in the case where $\rho_2/\rho_1 = 1.20$, when a_i/h_1 is relatively small, the opposite is true, when a_i/h_1 is relatively large.

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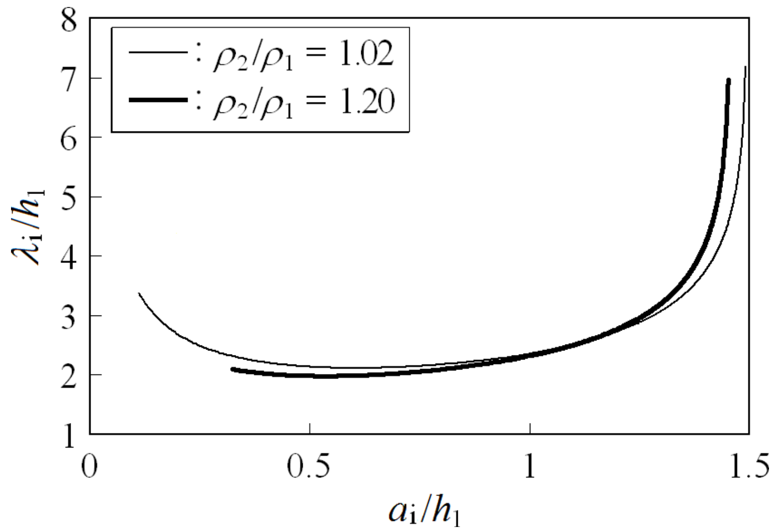

Fig. 15: Relationship between the relative representative wavelength λ_i/h_1 and the ratio of wave height to upper layer thickness in still water, a_i/h_1, for internal-mode internal solitary waves, where the representative wavelength λ_i is defined by Eq. (9), and $h_2/h_1 = 4.0$.

Figure 16 shows the relative phase velocity $C_i/C_{i,0}$ of internal-mode solitary waves, where $C_{i,0} = \sqrt{(\rho_2 - \rho_1) g h_1 h_2 / (\rho_2 h_1 + \rho_1 h_2)}$ is the phase velocity of linear internal shallow water waves without the coexistence of surface waves. The relative phase velocity $C_i/C_{i,0}$ is larger when $\rho_2/\rho_1 = 1.02$ than when $\rho_2/\rho_1 = 1.20$.

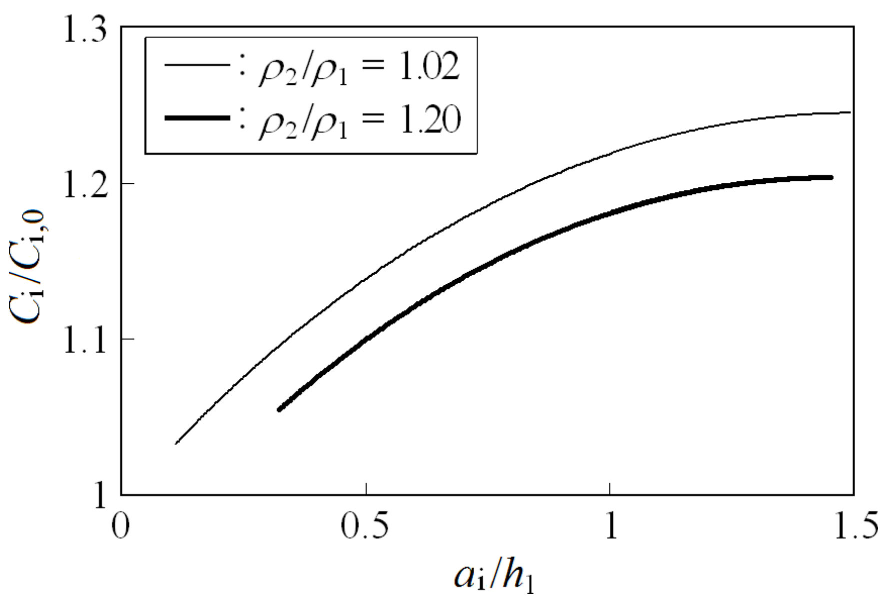

Fig. 16: Relationship between the relative phase velocity $C_i/C_{i,0}$ and the ratio of wave height to upper-layer thickness in still water, a_i/h_1, for internal-mode internal solitary waves, where $C_{i,0}$ is the phase velocity of linear internal shallow water waves without the coexistence of surface waves, and $h_2/h_1 = 4.0$.

Shown in Fig. 17 are the ratios of wave height, a_s/a_i, where a_s and a_i are the wave height of internal-mode surface and internal solitary waves, respectively. The wave height ratio a_s/a_i is larger when $\rho_2/\rho_1 = 1.20$ than when $\rho_2/\rho_1 = 1.02$. The numerical solutions for wave height ratio a_s/a_i decrease, as the relative wave height a_i/h_1 is increased, although that through the linear shallow water wave theory for the coexisting field of surface and internal waves does not depend on the relative wave height a_i/h_1, for $a_s/a_i = [(\rho_2/\rho_1) - 1] / [(\rho_2/\rho_1)/(h_2/h_1) + 1]$, such that $a_s/a_i \simeq 0.154$ when $\rho_2/\rho_1 = 1.20$, and $a_s/a_i \simeq 0.016$ when $\rho_2/\rho_1 = 1.02$.

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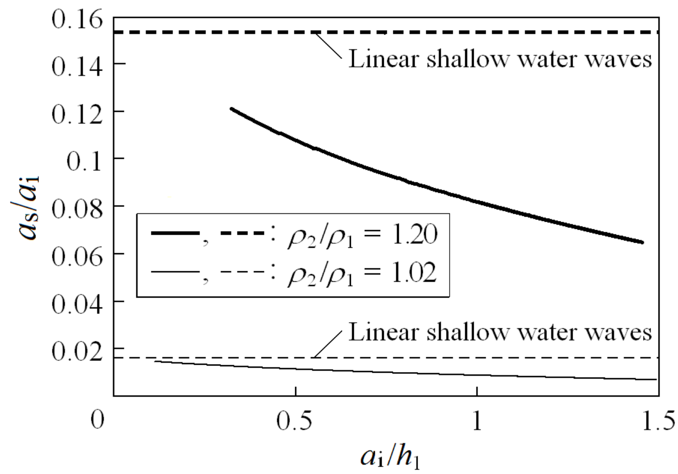

Fig. 17: Relationship between wave height ratio a_s/a_i and relative wave height a_i/h_1, where a_s and a_i are the wave height of internal-mode surface and internal solitary waves, respectively, and $h_2/h_1 = 4.0$.

VI. Conclusions

The numerical solutions for the solitary waves in the coexisting fields of surface and internal waves were obtained for the two-layer fluids with a free water surface, where the phases of both the steady surface and internal solitary waves were assumed to be the same, with a surface mode or an internal mode. The set of nonlinear equations based on the variational principle for steady waves were solved using the Newton-Raphson method.

The relative phase velocity of surface-mode solitary waves was smaller in the coexisting fields of surface and internal waves than in the cases without the coexistence of internal waves. The difference in the relative phase velocity between the two decreased, as the relative wave height of surface-mode surface solitary waves was increased.

The relative phase velocity of internal-mode solitary waves was also smaller in the coexisting fields of surface and internal waves than in the cases without the coexistence of surface waves. The difference in the relative phase velocity between the two decreased, as the relative wave height of internal-mode internal solitary waves was increased.

The interfacial position of the internal-mode internal solitary waves in the coexisting fields of surface and internal waves exceeded the critical level determined in the cases without the coexistence of surface waves.

The wave height ratio between internal-mode surface and internal solitary waves was smaller than the corresponding linear shallow water wave solution, and the difference increased, as the relative wave height of internal-mode internal solitary waves was increased.

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Analysis of Consequences of Unmanaged Wastes on Building Procurement Activities in Southwest, Nigeria

By Tongo, Samual O, Oluwatayo Adedayo, A, Ogungbemi, A.O. & Akingbade, O. H
Olabisi Onabanjo University

Abstract- This paper examines the consequences of unmanaged wastes on building procurement activities across southwest Nigeria. To achieve this, two hundred and six-one (461) questionnaires were randomly administered across the six (6) that makes of the southwest states Nigeria. The result of the findings established that 75.9% of unmanaged building material wastes have a direct impact on project cost, 69.3% of unmanaged wastes have a direct impact on the environment, 65.1% of the wastes have a direct impact on the socio-economic well-being of the general population and the quality of life respectively. The study further showed that 78.5% of unmanaged building material wastes have a direct impact on the loss of significant revenue, 73.6% of wastes have a direct impact on the lengthening of contract execution time, while, 72%, 62.5%, 61.7%, 60.9%, 58.5% and 51.3% of wastes have a direct impact on a cleaner environment, less productivity, others (such as land and air pollution, and public health), increased project cost, increased patronage and longer lifespan of materials respectively. The findings recommend the development of wastes management interventions should place dual emphasis on building procurement activities and professionals (e.g. architects, builders, engineers, project manager etc.) to effectively train on the ways of handling materials, and waste reduction.

Keywords: analysis, building procurement, consequences, unmanaged wastes, procurement activities, southwest.

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Keywords: analysis, building procurement, consequences, unmanaged wastes, procurement activities, southwest.

I. Introduction

The global burden of building material waste is enormous in terms of material wastage, percentage of project cost, time and cost overrun, and it is still growing specifically in Nigeria and many other developing countries in the light of housing and infrastructure development component of the sustainable development goals. Edoka et al. (2013); Wahab and Lawal (2011) in their studies corroborated the earlier submission that the activities of building and infrastructure development have been on the increase as a result of the strong demand from increasing population and urbanisation. This, in turn, has translated to a corresponding generation of an enormous amount of waste at the different stages of procuring building projects in the construction industry (that is from the inception stage, through the design stage to the implementation stage) and amounting to between 30% - 35% of the industrial waste globally per annum translating to several billion tonnes (Solis-Guzman et al., 2009).

This includes those wastes produced from the activities of maintenance and/or renovation of the buildings and demolition at the end of life. Olusanjo, Panos and Ezekiel (2014) reported that close to 30% of all construction works are made up of works that are being re-worked and they include all the unnecessary efforts of re-doing the processes/activities that were incorrectly implemented the first time. Similarly, findings from the literature showed that rework has become a major issue in construction procurement process leading to considerable time and cost overrun in projects. Some other studies (Burati et al., 1992; CIDA, 1994; Oyewole et al., 2011) opined that the direct cost of rework range between 5% and 15% of the total contract value and this figure could be higher considering the indirect costs and disruptions caused by schedule delays, litigation and other intangible aspects of poor quality finishes that come with it.

Gardiner (1994) in a similar study, estimated that the costs related to the rework of design consultants could be as high as 20% of their fee for a given project and that the primary sources of rework in construction, naturally, are the documentation upon which construction activities are based and they include design changes, errors and omissions (O'Connor and Tucker, 1986; Burati et al., 1992; Love et al., 1999). Abdul-Rahman (2013) reported that projects in their study area overshoot their original budget with about 14% of the final project cost (cost overrun) while Standish Group (2015) Chaos Report submitted that about 70% of all projects overshoot their projected delivery date (time overrun) and the projected cost with about 30% of the total cost of materials. The study by Olusanjo et al., 2014 reported that about 50% of labour is lost to inefficiencies and that only about 90% of the building materials purchased for a project are effectively used, the remaining 10% wasted. The waste generated from building and construction projects is therefore seen

Author α: Department of Architecture, Faculty of Environmental Studies, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.
e-mail: omolaraphilips@gmail.com
Author σ: Department of Architecture, College of Science and Technology, Covenant University, Ota, Ogun State, Nigeria.
Author ρ Ѡ: Department of Estate Management and Valuation, Lagos State Polytechnic, Ikorodu.

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to be huge and accounts for a sizeable proportion of the overall amount produced in many countries, making it the single largest waste stream (Bates, 2006).

Studies from developing country like Nigeria shows that it is a popular practice for a large portion of building wastes to be illegally dumped by roadsides, river banks and stockpiled in many other open spaces where some of them are either burnt or buried on the same site (Mahayuddin et al., 2008). It is noted that if these illegal dumping of building and construction debris are not checked, it has the propensity to affect the well-being of people, the value of properties and the cost of cleaning up the mess. Likewise, incineration of wastes leads to the generation of a large volume of nitrogen oxide gases that can potentially contribute to the existing environmental issues such as acidification and eco-toxicity with the volume of residual ashes attaining very high level with toxic substances (Qian, Cao, Chui and Tay, 2006), while Tan and Khoo (2006) claimed that the energy gained from the process outweighed the environmental damage associated with it.

Tongo, Oluwatayo, & Adeboye, (2020a), examined procurement waste management on building construction industry in southwestern, Nigeria, the study found that professional satisfactory index fell between ''disagree'' and ''not sure'' this translate that management support, staff knowledge, financial incentives/motivation, estimating/ordering practice, design issues, material Supply issues, material storage practice may not reduce the scourge of procurement waste in Building construction. In another study, Tongo, et, al, (2020), examined the Professional's Perception of Materials Management Practices on Construction Sites in selected states in Nigeria through the use of structured questionnaires, administered to senior construction professional personnel of construction firms, the study established that delay in the completion time of project such as storage of materials on-site with mean value (4.9), incompetence of estimators (4.8), issuing of materials for use (4.7) and procurement for materials (4.6).

The inappropriately managed waste has the potential to cause traffic obstruction, block storm water drains and other waterways thereby leading to flooding, unpleasant visual perception and general environmental degradation which impact on the health and safety of the workers as well as the socio-economic aspects of the society. Ordinarily, stockpiling of rubbles from construction works is considered useful as it could be used in earth filling/land reclamation projects on a later day (Poon, Yu and Ng, 2001). This was thought to be an efficient way of reusing inert materials but there are not enough of such projects to absorb the stockpiled wastes. It has, therefore, become increasingly difficult and uneconomic to sort inert materials for use by other projects as filling materials (Einstein Network, 2002). Also, a large portion of these wastes is buried or end up in landfills mostly in the industrialised nations due to their non-combustible nature. In the UK for example, about 89.6 million tonnes of waste was generated from construction-related activities in 2005 and out of which about 31% (that is, 28 million tonnes) went to the landfill. In Australia (between 2006 and 2007), about 7 million tonnes of waste was sent to the landfill (Olusanjo, et al., 2014).

Like in many other studies, Yu, Poon, Wong, Yip and Jaillon (2013) reported that the existing landfills in Hong Kong can no longer cope with the volume of waste disposed of in them daily while Hostovsky (2004) observed that in recent times, landfills could no longer provide the desired long term and sustainable solution to manage waste; hence they have become a headache to many cities. Finding new sites suitable for landfill activities has always been a tough task because they require large pieces of land, which have to fit well with the geological and engineering criteria (Hostovsky, 2004). Depountis, Koukis and Sabatakakis (2009) noted that more waste is presently being generated per capita and this has contributed to shortening the lifespan of many landfills significantly.

The absence of which has given rise to increased environmental problems like noise pollutions, emissions of dust and gases to the atmosphere and contaminated water and watercourses. Also, extending the existing sites is extremely costly (Yu, 2010). This land-use conflict was brought about by the 'Not-In-My-Backyard' syndrome and the more demanding administrative procedure imposed by the environmental impact assessment policies make the siting of new waste facilities a time-consuming and herculean task in many countries (Hostovsky, 2004).Material waste significantly attracts additional cost to the estimated cost of building projects as a result of the new purchases that have to be made to replace the wasted ones. The cost of demolition and executing previous unsatisfactory works, time losses due to delays and the cost of disposing of the waste are all included as waste and all add-up to the financial losses by the contractor (Ekanayake and Ofori, 2000). Hence, construction waste reduction is currently being accorded the highest priority amongst waste management options today which includes reduction, recycling and reuse.

II. Methodology

In this study, primary and secondary data were used. The primary data was attained through field survey, while secondary data were derived from published texts. To collect data and to meet the set objectives of this study two hundred and sixty-one (261) questionnaires were randomly administered among the built environment professionals (Architects, Builders, Engineers, Quantity Surveyor, Town Planners, and

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Project Manager etc.) across the six (6) states that made-up of southwest states of Nigeria namely Ekiti State, Lagos State, Ogun State, Ondo State, Oyo State and Osun State(detailed on table 2.1) using the Yemane (1967) formula n = N / 1+N (e)2 for calculating a finite population as cited by Gagungu (2012).

To assess the consequences associated with unmanaged wastes generated by the operations of building construction, the responses were given by the survey respondents to the research instrument's question on the effect of unmanaged building construction wastes on the environment; socio-economic well-being and quality of life; project cost was examined. However, only the professional in the senior cadre level was picked as a sample and administered the questionnaire to collect information about their knowledge, attitudes and current practices regarding the management of wastes from building construction processes, and the motivation to adopt any particular strategy was obtained. Data were analyzed using SPSS.

Table 2.1: Computed Sample Size of the Building Industry Professional in Southwest Nigeria

S/N	Professionally Registered Firms	Sample Population	Calculated Sample Size
1	Architects	281	103
2	Civil Engineers	53	37
3	Quantity Surveyor	83	53
4	Contractors	27	20
5	Client agencies	17	10
	Total	461	223

III. Findings and Discussions

To assess the consequences associated with unmanaged wastes generated by the operations of building construction, the responses were given by the survey respondents to the research instrument's question on the effect of unmanaged building procurement wastes on the environment; socio-economic well-being and quality of life; project cost was examined.

Table 3.1: Analysis of the Consequences of Unmanaged Waste Generated from Building Procurement Activities

	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Mean Score	Rank
Building material Waste impact on Project Cost	79(30.3)	119(45.6)	33(12.6)	21(8.0)	9(3.4)	3.91	1
Building material Waste impact on the Environment	70(26.8)	111(42.5)	20(7.7)	42(16.1)	18(6.9)	3.66	2
Building material Waste impact on the Socio-economic Well-Being and Quality of Life	59(22.6)	111(42.5)	36(13.8)	36(13.8)	19(7.3)	3.59	3

Source: Author Field Survey, 2020

The results (Table 3.1.), showed that majority (75.9%) of the respondents were in agreement that unmanaged building material wastes have a direct impact on project cost, it is also seen that 69.3% of the respondents are agreed that unmanaged wastes have a direct impact on the environment. While, many (65.1%), of the respondents, are agreed that unmanaged wastes have a direct impact on the socio-economic well-being of the general population and the quality of life respectively. Similarly, the study established that the effect of unmanaged waste on project cost is ranked highest with a mean score of 3.91, this is followed by the effect on the environment and finally the effect on the socio-economic well-being of the general population and the overall quality of life with mean scores of 3.66 and 3.59 respectively.

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Table 3.2: Analysis of the Danger of Unmanaged Building Material Waste

	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Mean Score	Rank
Direct impact on loss of significant revenue	76(29.1)	129(49.4)	22(8.4)	24(9.2)	10(3.8)	3.91	1
Direct impact on the lengthening of contract execution time	78(29.9)	114(43.7)	37(14.2)	24(9.2)	8(3.1)	3.88	2
Direct impact on cleaner environment	65(24.9)	123(47.1)	40(15.3)	21(8.0)	12(4.6)	3.80	3
Direct impact on less productivity	44(16.9)	119(45.6)	33(12.6)	50(19.2)	15(5.7)	3.49	4
Direct impact on others (such as availability of land; land, air and water qualities, and risk to security)	60(23.0)	101(38.7)	34(13.0)	36(13.8)	30(11.5)	3.48	5
Direct impact on increased project cost	48(18.4)	111(42.5)	29(11.1)	47(18.0)	26(10.0)	3.41	6
Direct impact on increased patronage	45(17.4)	106(41.1)	35(13.6)	44(17.1)	28(10.9)	3.37	7
Direct impact on longer lifespan of materials	40(15.3)	94(36.0)	53(20.3)	51(19.5)	23(8.8)	3.30	8

Source: Author Field Survey, 2020

The results of the further analysis of the data to assess the danger of unmanaged building material waste are as shown in table 3.2, revealed that as many 78.5% of the respondents were agreed that unmanaged building material wastes have a direct impact on the loss of significant revenue while 73.6% indicated that unmanaged wastes have a direct impact on the lengthening of contract execution time. In the same manner, 72%, 62.5%, 61.7%, 60.9%, 58.5% and 51.3% of the respondents are agreed that unmanaged wastes have a direct impact on a cleaner environment, less productivity, others (such as land and air pollution, and public health), increased project cost, increased patronage and longer lifespan of materials respectively. However, it is seen that the extent to which unmanaged building material waste affects the loss of significant revenue is perceived to be most affected with a mean score value of 3.91 followed by the impact on lengthening of contract execution time with a mean score of 3.88 and the impact on the cleaner environment with a mean score of 3.80.

IV. Conclusion

This study presents findings on the consequences of unmanaged wastes on building procurement activities in southwest states Nigeria. The finding is most significant to the current lag in building procurement activities in developing countries, where a substantial shortage was recorded due to poor waste management. The findings of this study indicate that wastes management interventions should place dual emphasis on building procurement activities and professionals (e.g. architects, builders, engineers, project manager etc.) to effectively train on the ways of handling materials, and waste reduction. There are needs for a further study assessing the effect of building procurement on project cost and construction projects applying international recognized building procurement indicators to examines and design a desired and better inform building procurement intervention strategies and regulatory decisions within the study area.

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Causes of Delays in Road Construction Projects in Laos

By Bounthipphasert Soumphonphakdy, Shozo Nakamura, Toshihiro Okumatsu & Takafumi Nishikawa
Nagasaki University

Abstract- One of the most important sectors in infrastructure development in Laos is road construction. However, many road construction projects in Laos suffer from extensive delays. This causes damage such as recurring problems in the road construction industry, and has a negative effect on the success of road construction projects in terms of schedule, cost, quality, safety and the amenity of road users. The goal of this study is to determine the main causes of these delays and to offer remedies. To identify the causes of delays, a questionnaire is designed by modifying one used to measure causes of delays in road construction projects in the West Bank in Palestine and in consultation with engineering experts with more than 10 years of experience in Laos road construction projects. A total of 53 causes of delay are identified as important in Laos. Questionnaire respondents included 35 contractors, 31 owners and 24 consultants in total. The survey results indicate that the five top factors causing road construction delays are: Contractor cash flow; Delayed payment by owner; Difficulties in financing project by contractor; Financial issues related to owner; and Insufficient equipment and vehicles for the work.

Keywords: *causes of delay; road construction projects; severity index; laos.*

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Causes of Delays in Road Construction Projects in Laos

Bounthipphasert Soumphonphakdy [α], Shozo Nakamura [σ], Toshihiro Okumatsu [ρ] & Takafumi Nishikawa [ω]

Abstract- One of the most important sectors in infrastructure development in Laos is road construction. However, many road construction projects in Laos suffer from extensive delays. This causes damage such as recurring problems in the road construction industry, and has a negative effect on the success of road construction projects in terms of schedule, cost, quality, safety and the amenity of road users. The goal of this study is to determine the main causes of these delays and to offer remedies. To identify the causes of delays, a questionnaire is designed by modifying one used to measure causes of delays in road construction projects in the West Bank in Palestine and in consultation with engineering experts with more than 10 years of experience in Laos road construction projects. A total of 53 causes of delay are identified as important in Laos. Questionnaire respondents included 35 contractors, 31 owners and 24 consultants in total. The survey results indicate that the five top factors causing road construction delays are: Contractor cash flow; Delayed payment by owner; Difficulties in financing project by contractor; Financial issues related to owner; and Insufficient equipment and vehicles for the work.

Keywords: causes of delay; road construction projects; severity index; laos.

I. Introduction

Laos is a landlocked developing country located in the heart of the Indochina Peninsular. It shares borders with five other countries (namely China, Myanmar, Thailand, Vietnam and Cambodia). Based on its strategic location, Laos has the potential to transform itself into a land-linked country developing connections with its neighbors through the road network and railways. Thus, development of the transportation infrastructure is one of the most important means of promoting the country's economic development. In the decades since independence in 1975, the Lao Government has invested significantly in infrastructure development, especially expanding and improving the road network.

The total length of the road network in Laos is over 60,340 km, including 552 km of reinforced concrete (RC) roads, 1,203 km of asphalt concrete (AC), 9,973 km of double bituminous surface treatment (DBST), 23,179 km of gravel and 25,433 km non-paved. There is still a lack of annual budgets for road maintenance, rehabilitation and upgrading to ensure standards and improved road safety.

As in many countries, road construction projects often fall behind schedule in Laos. In fact, 36 of 59 ongoing projects in January 2020 had been behind schedule. This is an important issue affecting the management of road construction projects. There is a need to study the main causes of such delays and search for solutions that improve the situation. Delays in road construction have many negative impacts, such as budget over-runs and effects on the economy, the environment and other areas. They particularly affect those who use the roads and/or live near roads under construction, both directly and indirectly. The causes of road construction delays vary by country. Thus, it is important to determine the main common causes of delay in road construction projects in Laos.

In this study, a questionnaire survey was carried out. The questionnaire was designed by modifying one used to measure causes of delays in road construction projects in the West Bank in Palestine [1] and in consultation with engineering experts with more than 10 years of experience in Laos road construction projects, and sent to contractors, owners and consultants.

The main objectives of this study are the following:

- To identify the causes of delays in road construction projects in Laos;
- To rank the causes of delays in road construction projects in Laos;
- To identify the severity of delay causes from the perspective of contractors, owners and consultants;
- To test agreement on the ranking of the severity of delay causes among contractors, owners and consultants;
- To find ways to eliminate the causes of delays in road construction projects in Laos;
- To provide this research data to owners, consultants, contractors and designers for use in preparing and planning road construction; and
- To provide knowledge for engineers and the general public interested in the analysis of factors that cause problems due to delays in road construction projects in Laos.

Author α: Graduate School of Engineering, Nagasaki University, 1-14, Bunkyo-machi, Nagasaki 852-8521, Japan.
e-mail: soumphonphakdy_1011@yahoo.co.jp
Author σ: Department of Civil and Environmental Engineering, Nagasaki University, 1-14, Bunkyo-machi, Nagasaki 852-8521, Japan.
e-mail: shozo@nagasaki-u.ac.jp
Author ρ ω: Department of Civil and Environmental Engineering, Nagasaki University, 1-14, Bunkyo-machi, Nagasaki 852-8521, Japan.

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II. Literature Review

Many articles have reported studies on the causes of delay in construction projects. For example, Mahamid et al. [1] found that there are 52 possible causes of delay in road construction projects. Among these, 18 had a severity index (see eq. (1)) of over 60%, indicating a high or very high impact. A.M. Odeh and H.T. Battaomeh [2] used a survey to study the delays arising in construction projects with traditional contracts from the viewpoint of construction contractors and consultants. Results indicated that there was agreement among contractors and consultants that owner interference, inadequate contractor experience, financing and payments, labor productivity, slow decision making, improper planning, and subcontractors are among the top ten most important factors. Y. Frimpong et al. [3] found that delays and cost overruns are common in construction projects and groundwater development projects in Ghana. Their survey included personnel from owners, consultants and contractors involved in groundwater-related projects. The main causes of delays and cost overruns included difficulty in obtaining monthly payments from agencies; poor contract management; material procurement; poor technical performance; and material price inflation. The study concluded that effective project planning, control and monitoring should be established to enhance project performance in order to minimize or avoid delays and cost problems in groundwater-related projects. J.A. Alsuliman [4] investigated the causes of delays in Saudi public construction projects and categorized them based on the various stages of a project, namely (1) factors before the award of tenders, (2) factors during the award of tenders, (3) factors after the award of tenders, and (4) general factors. Through the use of a focus group, this study identified 50 delay factors. A questionnaire was administered and distributed to 211 people involved in the construction industry. From the results, the top 20 causes of delay were identified. A final simplified formula was developed to calculate the effect of each cause of delay on site. A case study was carried out to determine the percent time delay compared with the master schedule using the developed simpfied formula. Banobi E.T.B. and W. Jung [5] investigated 82 owner-side experts and 106 contractor-side experts in Tanzanian power construction projects. In successful projects (less than 10% time delay), the owners and contractors gave weight to similar causes, including vandalism and permits from authorities. Both suggested similar mitigation strategies such as close supervision, capacity building training, and proper logistics management. On the other hand, in the case of unsuccessful projects (more than 10% time delay), they exhibited many different responses. In particular, contractors gave more weight than contractors to causes such as changes in scope, poor supervision by the owner, delays in approval, planning failures, and design risks. Owners on the other hand gave more weight to mitigation strategies such as top management support and timely procurement. R.F. Aziz and A.A. Abdel-Hakam [6] investigated strategies to effectively overcome road construction delays in developing countries, concluding with suggestions for fundamental and large-scale reform of procurement systems and stakeholder management. Khatib, B.A., Poh, Y.S. and El-Shafie [7] conducted fourteen interviews with project managers, construction managers, and senior site engineers to identify the factors they faced that led to delays in a reconstruction project. The identified factors were divided into two groups: one related to the demolition phase (five factors) and the second related to reconstruction work (nine factors). The supply of building materials during the reconstruction phase was considered one of the major delaying factors and 14 delay factors were identified that should be carefully considered to assure the sustainability of the main objective during reconstruction activities. A. Orangi et al. [8] found that delays could lead to some serious time and/or cost overrun issues, thereby adversely affecting contractors, clients and other stakeholders to different degrees. They concluded that consolidating knowledge from related research and lessons from recent projects would be beneficial for rationalized project management. In particular, identifying significant root causes of delays and then developing suitable management methods (e.g. prevention measures) are essential to effectively ensuring successful project outcomes.

M.H. Fallahnejad [9] set out to identify and rank the causes of delays in gas pipeline projects in Iran. 24 completed gas pipeline projects were studied and the extracted delay factors were discussed with 10 experts from several disciplines. The result was a 43-item list of factors, which were then ranked by means of a questionnaire survey. The 10 major delay factors were found to be the following: imported materials, unrealistic project timescale, client-related materials, land expropriation, change orders, contractor selection methods, payments to contractor, obtaining permits, suppliers, and contractor's cash flow". Majed Alxara et al. [10] studied the issues faced by Saudi Arabia in completing construction projects on time and on budget. It has been documented that 70% of public construction projects are delayed in the country. A case study was performed at a university campus in northern Saudi Arabia, identifying the major causes of project delays. The university had experienced delays ranging from 50% to 150%. The study proposed solutions for minimizing the nine major delay factors. A literature research identified one construction management method, the Performance Information Procurement System (PIPS), that has been documented multiple times to improve project performance and minimize

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delays. B.-G. Hwang et al. [11] looked at reducing wait times for future public housing owners, which requires such projects to be completed on time. A survey of 36 industry experts revealed that "site management", "coordination among various parties", and "availability of laborers on site" were the top three factors affecting the schedule performance of public housing projects in Singapore. In findings from a case study, Raj Shah [12] clarified that the most influential factors in Australia are (1) planning and scheduling deficiencies, (2) methods of construction, (3) effective monitoring and feedback processes, which contrasts with Ghana where they were (1) delays in payment certificates (2) underestimating of project cost, (3) project complexity. On the other hand, in Malaysia the most influential factors are (1) improper planning by contractors, (2) poor site management, and (3) inadequate contractor experience. It is clear that the factors causing project delays and cost overruns are diverse and vary from one country to another. N.D. Long et al. [13] presented problems with large construction projects in Vietnam. Data analysis revealed that the problems could be grouped underfive major headings: (1) incompetent designers/contractors, (2) poor estimation and change management, (3) social and technological issues, (4) site related issues, and (5) improper techniques and tools. Michał Gałuszak and Agnieszka Leśniak [14] carried out a survey and multivariate statistical analysis of client's ideas about construction delays in Poland. They found that timely implementation of construction work (at the scheduled time) is vital for both the investor and the contractor. Even perfectly planned and organized projects run the risk of delays. Despite many tools supporting construction management, delays keep occurring in construction projects. S.O. Ogun Lana et al. [15] took the view that construction industry problems in developing economies can be nested in three layers: (a) problems of shortages or inadequacies in industry infrastructure (mainly supply of resources); (b) problems caused by clients and consultants and (c) problems caused by contractor incompetence/inadequacies.

III. Research Methodology

a) Questionnaire Design

In this paper, based on work in the literature [1], a questionnaire was developed in consultation with civil engineers who had more than 10 years of experience in road construction projects in Laos. Final modifications were made to accommodate the whole range of information about effective causes of delay in road construction projects in Laos. A total of 53 possible causes were included in the questionnaire.

In terms of structure, the questionnaire was designed to have two main parts. Part I is related to respondents' personal information, including whether they are contractors, owners or consultants. It includes questions pertaining to their experience in the construction industry. Part II includes the list of the identified causes of delay in road construction projects in Laos. These causes are classified into eight main groups as shown in Table 1 according to the source of delay: project, owner, contractor, consultant, design, laborers, materials and equipment, and external. For each cause a question was asked about its degree of severity in terms of contributing to project delay. Severity was categorized into six-levels as follows: level 0 = no influence; level 1 = very low; level 2 = low; level 3 = moderate; level 4 = high; and level 5 = very high.

Table 1: List of Possible Delay Causes and Groupings

Main group	Causes under each group	
1. Project group	1	Low project bid price
	2	Construction area restricted
	3	Inconvenient site access
	4	Poor ground conditions
	5	Poor soil quality
	6	Poor terrain conditions
2. Owner group	7	Delayed payment by owner
	8	Delayed decision by owner
	9	Coordination between owner and contractor.
	10	Unreasonable project timeframe
	11	Financial issues related to owner
	12	Project delayed by owner
	13	Delayed approval of materials
	14	Not well-defined scope of work
	15	Delayed land expropriation by owner
	16	Change order from owner during construction
	17	Late issue of approval documents by owner.
	18	Unclear assignment of responsibility near province boundaries

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3. Contractor group	19	Difficulties in financing project by contractor
	20	Poor communication between contractor and other parties
	21	Conflict between contractor and other parties
	22	Poor resource management
	23	Necessity to re-do work due to contractor failings
	24	Ineffective planning management by contractor
	25	Insufficiently skilled technical staff
	26	Insufficient equipment and vehicles for the work
	27	Poor quality control
	28	Improper construction method
	29	Contractor cash flow
4. Consultant group	30	Consultant too lenient
	31	Poor coordination between the consultant and contractor(s)
	32	Delay in implementing inspection by consultant
	33	Poorly qualified inspector
	34	Insufficient inspectors
5. Design group	35	Delayed design work
	36	Mistakes in design
	37	Inappropriate design
6. Laborers group	38	Low labor productivity
	39	Insufficiently skilled equipment operator
	40	Insufficient laborers
	41	Personal conflict between laborers and management team
	42	Personal conflict among laborers
7. Materials and equipment group	43	Lack of equipment efficiency
	44	Shortage of equipment
	45	Changes in material types and specifications during construction
	46	Shortage in materials
8. External group	47	Political situation
	48	Exchange rate fluctuation under contract
	49	Change in loans policy by bank
	50	Weather conditions
	51	Monopoly market
	52	Oil price increase
	53	Public events

b) *Data Analysis*

i. *Ranking of Delay Causes*

The suggested delay causes were ranked by severity index. The following formula was used to rank them on the basis of impact level as identified by the participants:

$$\text{Severity index (\%)} = \sum a(n/N)*100/5 \qquad (1)$$

where a = severity level, which ranges from 0 for no influence up to 5 for very high, n = frequency of response and N = total number of responses.

Accordingly, if all participants respond that a particular cause has no influence, then that cause gains a severity index of 0, meaning that it is not relevant to project delays and ranks last. Conversely, if all respond that it has a very high influence, then the severity index is 100, meaning that this cause is very highly relevant and is the first in rank. Table 2 shows the possible ranges for the severity index and the corresponding impact level.

Table 2: Severity Index and Corresponding Impact Level

Severity index (%)	Impact level
0	No influence
0-20	Very low
20-40	Low
40-60	Moderate
60-80	High
80-100	Very high

The severity index for each cause was calculated according to Eq. (1) from the individual contractors', owners' and consultants' responses as well as from the combined responses.

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A group index was calculated by using the average of the severity indexes of the causes in each group such that

$$\text{Group severity index (\%)} = \sum_{i=1}^{n} X_i / n \qquad (2)$$

where Xi = severity index of cause i in the group and n = number of causes in the group.

ii. *Rank Correlation*

The Spearman rank correlation was used to measure the correspondence between pairs of rankings in the sample observations, thereby comparing how well the contractors, owners and consultants agree on the causes of delay. A perfect positive correlation ($r_s = +1$) indicates that the object is ranked identically in the compared samples, whereas a perfect negative correlation ($r_s = -1$) indicates that the rankings have an exactly inverse relationship. This means that sample correlations close to unity in magnitude imply a good correlation, whereas values near 0 indicate low or no correlation. The Spearman rank correlation formula is as follows:

$$r_s = 1 - \left[6 * \sum d^2 / (n^3 - n) \right] \qquad (3)$$

Where rs = Spearman rank correlation coefficient between two parties, d = difference between ranks assigned to variables for each cause and n = number of pairs of rankings.

IV. Results and Discussions

a) Respondent Personal Information

The questionnaire was sent to a total of 50 contractors, 40 owners and 30 consultants. A total of 35 contractors (70.0%), 31 owners (77.5%) and 24 consultants (80.0%) completed the questionnaire as shown in Table 3. All of the respondents were engineers. Among them, 30 had between 5 and 10 years of experience, 18 had 10 to 15 years of experience and 42 had over 15 years of experience. The average was approximately 16 years' experience.

Table 3: List of Responses (percent)

Respondents	Questionnaire distributed	Responses returned	Percentage of responses
Contractors	50	35	70.0%
Owners	40	31	77.5%
Consultants	30	24	80.0%
Total	120	90	75.0%

b) Ranking of Delay Causes by Group

i. *Project Group*

Six delay causes are listed in this group. Table 4 shows the severity index and ranking of each one from the viewpoint of contractors, owners and consultants, as well as the combined viewpoint (the combination of contractor, owner and consultant views). It is clear that the most severe cause of delays from the combined viewpoint is "Low project bid price". However, the rankings from the individual viewpoints are quite different.

The results also show that the difference between the most and least severe causes in this group is 37.22%.

Table 4: Ranking of Delay Causes in Project Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Low project bid price	60.00	1	76.57	1	39.35	5	62.50	1
Poor soil quality	46.89	2	43.43	6	47.10	1	51.67	2
Poor terrain conditions	46.22	3	48.00	4	45.81	2	44.17	3
Poor ground conditions	45.11	4	47.43	5	45.81	2	40.83	4
Inconvenient site access	43.78	5	50.86	2	40.65	4	37.50	6
Construction area restricted	42.67	6	49.14	3	38.71	6	38.33	5

ii. *Owner Group*

This group includes twelve causes. Table 5 presents the rankings from each viewpoint, showing that the most severe cause from all viewpoints is "Delayed payment by owner".

The most severe causes in the rankings by contractors, owners, consultants and the combined view are quite similar, with 1 to 3 in the rankings being "Delayed payment by owner", "Financial issues related to owner" and "Delayed decision by owner",

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respectively, except in the case of owners and consultants.

The results also indicate that the most severe causes in this group are quite distinct. In the combined view, for example, there is a wide span of severity ranging from 38.00% to 81.56%, a difference of 43.56%. That is, the causes range from low to very high severity and the difference in its severity index.

Table 5: Ranking of Delay Causes in Owner Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Delayed payment by owner	81.56	1	91.43	1	73.55	1	77.50	1
Financial issues related to owner	75.11	2	85.71	2	68.39	2	68.33	2
Delayed decision by owner	57.33	3	71.43	3	48.39	4	48.33	4
Change order from owner during construction	51.33	4	57.71	8	45.81	5	49.17	3
Coordination between owner and contractor.	49.78	5	60.00	6	43.87	6	42.50	8
Late issue of approval documents by owner.	49.56	6	61.14	5	40.65	8	44.17	6
Unreasonable project timeframe	49.33	7	50.86	10	52.26	3	43.33	7
Not well-defined scope of work	48.00	8	58.86	7	41.94	7	40.00	11
Delayed land expropriation by owner	47.11	9	53.14	9	40.65	8	46.67	5
Delayed approval of materials	46.89	10	63.43	4	37.42	10	35.00	12
Project delayed by owner	41.33	11	48.00	11	32.90	11	42.50	8
Unclear assignment of responsibility near province boundaries	38.00	12	44.57	12	28.39	12	40.83	10

iii. *Contractors Group*

There are eleven causes in the contractors group. Table 6 shows that the cause with the highest severity from the combined, contractors', owners' and consultants' views is "Contractor cash flow". The top and second ranked causes from all viewpoints are quite similar. In the combined view, the range of severity for all causes is narrow, ranging from 46.22% to 84.22%, meaning that the effect on delays is moderate to very high.

Table 6: Ranking of Delay Causes in Contractor Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Contractor cash flow	84.22	1	88.00	1	78.71	1	85.83	1
Difficulties in financing project by contractor	77.11	2	82.29	2	75.48	2	71.67	3
Insufficient equipment and vehicles for the work	70.89	3	77.71	3	61.29	3	73.33	2
Poor quality control	63.11	4	71.43	4	54.19	6	62.50	5
Insufficiently skilled technical staff	59.78	5	61.14	5	57.42	4	60.83	6
Ineffective planning management by contractor	57.33	6	52.00	7	57.42	4	65.00	4
Improper construction method	56.00	7	58.29	6	49.68	8	60.83	6
Poor communication between contractor and other parties	52.00	8	49.71	9	52.90	7	54.17	8
Necessity to re-do work due to contractor failings	49.78	9	50.29	8	46.45	10	53.33	9
Poor resource management	46.44	10	49.71	10	41.94	11	47.50	11
Conflict between contractor and other parties	46.22	11	42.86	11	47.74	9	49.17	10

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iv. *Consultant Group*

Table 7 shows the severity index and ranking of each cause under the consultants group. five causes are identified under this group.

Table 7 shows the results that the most severe cause from the combined view, owners' view and consultants' view is "Insufficient inspectors". It is clear from the results that the severity index ranking from the combined view has a narrow span, with severity indexes ranging from 41.33% to 52.00%. That is, all causes in this group have a moderate effect on road construction project delays.

Table 7: Ranking of Delay Causes in Consultant Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Insufficient inspectors	52.00	1	68.00	2	43.23	1	40.00	1
Delay in implementing inspection by consultant	50.44	2	70.86	1	39.35	4	35.00	3
Poor coordination between the consultant and contractor(s)	47.78	3	61.71	4	40.65	2	36.67	2
Poorly qualified inspector	47.78	3	65.71	3	38.71	5	33.33	4
Consultant too lenient	41.33	5	52.00	5	40.65	2	26.67	5

v. *Design Group*

Table 8 shows the severity index and ranking of each cause in the design group. The most severe of the three causes in this group is "Delayed design work" for all viewpoints. The rankings from the contractors', owners', consultants' and combined views are all similar. The span of severity values in the combined view is quite narrow, ranging from 44.22% to 48.22%. That is, all causes in this group have a moderate effect on road construction project delays.

Table 8: Ranking of Delay Causes in Design Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Delayed design work	48.22	1	46.29	1	47.74	1	51.67	1
Mistakes in design	46.22	2	44.57	2	45.16	2	50.00	2
Inappropriate design	44.22	3	44.57	3	44.52	3	43.33	3

vi. *Laborers Group*

Table 9 shows the severity index and ranking of each cause in the laborers group. Five causes are identified in this group. All viewpoints except owners find that "Insufficient laborers" is the most severed delay cause; this ranks second for owners.

All of the rankings in Table 9 are quite similar. The severity index from the combined view ranges from 39.78% to 63.33%, meaning that these delay causes have an impact ranging from low to high.

Table 9: Ranking of Delay Causes in Laborers Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Insufficient laborers	63.33	1	68.57	1	50.97	2	71.67	1
Insufficiently skilled equipment operator	61.33	2	68.57	2	52.90	1	61.67	2
Low labor productivity	58.22	3	68.00	3	50.97	2	53.33	3
Personal conflict between laborers and management team	43.11	4	44.00	4	41.94	4	43.33	4
Personal conflict among laborers	39.78	5	40.00	5	36.77	5	43.33	4

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vii. *Materials and Equipment Group*

The material and equipment group comprises four delay causes. Table 10 shows that the most severe cause in the combined view is "Lack of equipment efficiency". The rankings from the contractors', owners' and combined views are quite similar, while consultants rank "Lack of equipment efficiency" third. However, first, second and third most severe causes are all grouped together.

The range of severity index values from the combined view is narrow, with values from 55.11% to 65.33%. That is, their impact on project delays ranges from moderate to high.

Table 10: Ranking of Delay Causes in Materials and equipment Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Lack of equipment efficiency	65.33	1	74.86	2	56.77	1	62.50	3
Shortage of equipment	65.11	2	75.43	1	52.26	2	66.67	1
Shortage in materials	58.22	3	61.71	3	48.39	3	65.83	2
Changes in material types and specifications during construction	55.11	4	61.14	4	44.52	4	60.00	4

viii. *External Group*

Seven delay causes are listed in the external group. Table 11 shows that the most severe cause from all viewpoints is "Oil price increase". There is no significant difference in the ranking of causes among the viewpoints. There is a wide span of severity index in the combined ranking, ranging from 30.00% to 64.67%. This indicates that these delay causes have an impact ranging from low to high.

Table 11: Ranking of Delay Causes in External Group

Cause	Combined' view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Oil price increase	64.67	1	80.00	3	55.48	1	54.17	1
Change in loans policy by bank	64.22	2	80.57	1	55.48	1	51.67	2
Exchange rate fluctuation under contract	58.44	3	80.57	1	44.52	4	44.17	3
Monopoly market	53.33	4	78.29	4	37.42	6	37.50	5
Weather conditions	46.22	5	48.57	5	45.16	3	44.17	3
Public events	42.22	6	45.14	6	42.58	5	37.50	5
Political situation	30.00	7	40.57	7	22.58	7	24.17	7

c) *Overall Ranking of Delay Causes*

The severity index and ranking of all investigated 53 causes of delay in road construction projects from the four viewpoints are listed in Table 12.

There are two causes with a severity index above 80% in the combined viewpoint: "Contractor cash flow" and "Delayed payment by owner". There are also three causes with a severity index above 70%: "Difficulties in financing project by contractor", "Financial issues related to owner" and "Insufficient equipment and vehicles for the work". A discussion on these top five delay causes from combined viewpoint can be made as follows.

- Contractor cash flow

The issue of contractor cash flow is found to be the top cause of delays in road construction projects in Laos. Many contracting companies in Laos are not only involved in road construction projects, so they have many other activities going on and may have taken on more contracted projects than cash flow can support. As a result, many contractors have put revolving money into other projects. Further, this problem commonly results from the second-ranked cause of delays according to the combined viewpoint: "Delayed payment by owner". Payments may be overdue for a particular project or, in some cases, payments from previously completed projects for the same owner are delayed [16]. These are important causes of "Contractor cash flow".

- Delayed payment by owner

"Delayed payment by owner" is the second-ranked cause of project delays. It has a number of causes, including: project cost exceeds original estimate; payments are staged and payment approval is

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slow; lack of clear payment guidelines; and increased project cost because of loan interest. Especially, disaster-recovery projects often cost more than the initial estimate.

Late payment appears to be a critical cause of delays in other countries, such as the West Bank in Palestine [1] (rank 4), Saudi Arabia[17][18] (rank 2 in both studies), Kuwait [19] (rank 2), Malaysia [20] (rank 4), Ghana [3] (rank 1), and Nigeria [21] (rank 2).

- Difficulties in financing project by contractor

Many contractors have difficulties in financing projects in Laos. This has some connection with the second-ranked cause of delays: "Delayed payment by owner". Also, contractors may be taking on business projects beyond their capability to invest because of insufficient financial resources; they may have poor cash flow management; and most road construction projects in Laos require the contractor to cover the investment required until the project is accepted by the owner (generally the Laos government), after which payment is made according to the contract. The owner usually pays in stages for 3 to 7 years after completion depending on the size of the project and annual budget plan.

- Financial issues related to owner

There are a number of factors relating to the financial status of the owner that can cause problems, such as: approvals of additional projects not included in the original annual master plan; the project has a much higher value than originally estimated; and payment approvals from owner delayed, so interest accrues on project cost. Also, in many cases of disaster-recovery projects, the quantity of work turns out to be higher than originally estimated.

- Insufficient equipment and vehicles for the work

Many road construction projects in Laos have to be carried out using less equipment and vehicles than initially specified in the contract. Further, the quality of equipment and/or vehicles is sometimes inadequate. The causes of this issue may be the insufficient examination of the contract documents. It is not unknown for a contractor to have another ongoing project at the same time and to move some equipment and/or vehicles to that project.

Only three causes have a severity index of less than 40% in the combined viewpoint, meaning that they have a low impact level: "Personal conflicts among laborers"; "Unclear assignment of responsibility near province boundaries"; and "Political situation".

Table 12: Overall Ranking of Delay Causes

Cause	Combined view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Contractor cash flow	84.22	1	88.00	2	78.71	1	85.83	1
Delayed payment by owner	81.56	2	91.43	1	73.55	3	77.50	2
Difficulties in financing project by contractor	77.11	3	82.29	4	75.48	2	71.67	4
Financial issues related to owner	75.11	4	85.71	3	68.39	4	68.33	6
Insufficient equipment and vehicles for the work	70.89	5	77.71	9	61.29	5	73.33	3
Lack of equipment efficiency	65.33	6	74.86	12	56.77	8	62.50	10
Shortage of equipment	65.11	7	75.43	11	52.26	14	66.67	7
Oil price increase	64.67	8	80.00	7	55.48	9	54.17	17
Change in loans policy by bank	64.22	9	80.57	5	55.48	9	51.67	21
Insufficient laborers	63.33	10	68.57	16	50.97	16	71.67	4
Poor quality control	63.11	11	71.43	13	54.19	11	62.50	10
Insufficiently skilled equipment operator	61.33	12	68.57	16	52.90	12	61.67	13
Low project bid price	60.00	13	76.57	10	39.35	44	62.50	10
Insufficiently skilled technical staff	59.78	14	61.14	24	57.42	6	60.83	14
Exchange rate fluctuation under contract	58.44	15	80.57	5	44.52	30	44.17	30
Low labor productivity	58.22	16	68.00	18	50.97	16	53.33	19
Shortage in materials	58.22	16	61.71	22	48.39	19	65.83	8
Delayed decision by owner	57.33	18	71.43	13	48.39	19	48.33	27

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Ineffective planning management by contractor	57.33	18	52.00	32	57.42	6	65.00	9
Improper construction method	56.00	20	58.29	29	49.68	18	60.83	14
Changes in material types and specifications during construction	55.11	21	61.14	24	44.52	30	60.00	16
Monopoly market	53.33	22	78.29	8	37.42	48	37.50	45
Insufficient inspectors	52.00	23	68.00	18	43.23	34	40.00	42
Poor communication between contractor and other parties	52.00	23	49.71	37	52.90	12	54.17	17
Change order from owner during construction	51.33	25	57.71	30	45.81	25	49.17	25
Delay in implementing inspection by consultant	50.44	26	70.86	15	39.35	44	35.00	49
Coordination between owner and contractor.	49.78	27	60.00	27	43.87	33	42.50	38
Necessity to re-do work due to contractor failings	49.78	27	50.29	36	46.45	24	53.33	19
Late issue of approval documents by owner.	49.56	29	61.14	24	40.65	39	44.17	30
Unreasonable project timeframe	49.33	30	50.86	34	52.26	14	43.33	34
Delayed design work	48.22	31	46.29	44	47.74	21	51.67	21
Not well-defined scope of work	48.00	32	58.86	28	41.94	36	40.00	42
Poorly qualified inspector	47.78	33	65.71	20	38.71	46	33.33	51
Poor coordination between the consultant and contractor(s)	47.78	33	61.71	22	40.65	39	36.67	48
Delayed land expropriation by owner	47.11	35	53.14	31	40.65	39	46.67	29
Delayed approval of materials	46.89	36	63.43	21	37.42	48	35.00	49
Poor soil quality	46.89	36	43.43	50	47.10	23	51.67	21
Poor resource management	46.44	38	49.71	37	41.94	36	47.50	28
Weather conditions	46.22	39	48.57	40	45.16	28	44.17	30
Mistakes in design	46.22	39	44.57	46	45.16	28	50.00	24
Conflict between contractor and other parties	46.22	39	42.86	51	47.74	21	49.17	25
Poor terrain conditions	46.22	39	48.00	41	45.81	25	44.17	30
Poor ground conditions	45.11	43	47.43	43	45.81	25	40.83	40
Inappropriate design	44.22	44	44.57	46	44.52	30	43.33	34
Inconvenient site access	43.78	45	50.86	34	40.65	39	37.50	45
Personal conflict between laborers and management team	43.11	46	44.00	49	41.94	36	43.33	34
Construction area restricted	42.67	47	49.14	39	38.71	46	38.33	44
Public events	42.22	48	45.14	45	42.58	35	37.50	45
Consultant too lenient	41.33	49	52.00	32	40.65	39	26.67	52
Project delayed by owner	41.33	49	48.00	41	32.90	51	42.50	38
Personal conflict among laborers	39.78	51	40.00	53	36.77	50	43.33	34
Unclear assignment of responsibility near province boundaries	38.00	52	44.57	46	28.39	52	40.83	40
Political situation	30.00	53	40.57	52	22.58	53	24.17	53

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d) Top Five Causes of Delay from each viewpoint

The top five delay causes from each viewpoint are picked up from Table 12 and listed in Tables 13-15 with their related groups. They are similar, and three causes, "Delayed payment by owner", "Contractor cash flow" and "Difficulties in financing project by contractor", are included in all tables. "Insufficient equipment and vehicles for the work" is included in the tables from owners' and consultants' viewpoint, indicating that there is only one cause different between them. It can be said that the recognition of the important causes of project delay is basically shared among contractors, owners and consultants. However, the level of the severity evaluated by contractors, owners and consultants is different. Severity indexes from the contractors' viewpoint are considerably higher than from the owners' and consultants' viewpoint. This fact can be also recognized from Table 12.

Table 13: Top Five Delay Causes and Related Groups from Contractors' Viewpoint

Cause	Related group	Severity index (%)	Rank
Delayed payment by owner	Owner	91.43	1
Contractor cash flow	Contractor	88.00	2
Financial issues related to owner	Owner	85.71	3
Difficulties in financing project by contractor	Contractor	82.29	4
Change in loans policy by bank	External	80.57	5

Table 14: Top Five Delay Causes and Related Groups from Owners' Viewpoint

Cause	Related group	Severity index (%)	Rank
Contractor cash flow	Contractor	78.71	1
Difficulties in financing project by contractor	Contractor	75.48	2
Delayed payment by owner	Owner	73.55	3
Financial issues related to owner	Owner	68.39	4
Insufficient equipment and vehicles for the work	Contractor	61.29	5

Table 15: Top Five Delay Causes and Related Groups from Consultants' Viewpoint

Cause	Related group	Severity index (%)	Rank
Contractor cash flow	Contractor	85.83	1
Delayed payment by owner	Owner	77.50	2
Insufficient equipment and vehicles for the work	Contractor	73.33	3
Difficulties in financing project by contractor	Contractor	71.67	4
Insufficient laborers	Laborers	71.67	4

e) Ranking of Groups

For this study, the causes of delay were classified into eight groups as described above. Here, these groups are ranked according to the grouped severity index of their causes as determined by contractors, owners, consultants. The results are presented in Table 16.

From the combined viewpoint, the three top groups are: Materials and equipment; Contractor; and Laborers. The range of severity index is narrow, from 46.22% to 60.94%. The top three groups from the contractors' viewpoint are: Materials and equipment; External; and Consultant. Those from owners' and consultants' viewpoint are the same: Contractor; Materials and equipment; and Laborers. The group with the lowest severity index is the Project group from contractors' viewpoint, and the Consultant group from owners' and consultants' viewpoint. Again, the group ranking from owners' and consultants' viewpoint is quite similar.

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Table 16: Group Ranking

Group	Combined view		Contractors' view		Owners' view		Consultants' view	
	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank	Severity index (%)	Rank
Materials and equipment	60.94	1	68.29	1	50.48	2	63.75	1
Contractor	60.26	2	62.13	5	56.66	1	60.26	2
Laborers	53.16	3	57.83	6	46.71	3	53.16	3
Owner	52.94	4	62.19	4	46.18	4	48.19	5
External	51.30	5	64.82	2	43.32	6	41.90	7
Consultant	47.87	6	63.66	3	40.52	8	34.33	8
Project	47.44	7	45.06	8	42.90	7	45.83	6
Design	46.22	8	45.14	7	45.81	5	48.33	4

f) Severity rank correlation

The Spearman rank correlation is used to measure the correspondence between contractors' and owners' responses, contractors' and consultants' responses, and owners' and consultants' responses. Equation (3) is used for this purpose. There is relatively good agreement (positive correlation) between contractors' and owners' rankings of delay causes, with rs = +0.474. There is also good agreement between contractors and consultants, with rs = +0.465. Between owners and consultants, the correlation is rs = +0.831, which is a very good relative agreement between the two parties in the ranking of delay causes. This may be because the consultant is usually the agents acting owners' behalf.

V. Recommendations to Reduce delays in road Construction Projects in Laos

The following recommendations are made to all parties as ways to reduce and control delays in road construction projects:

The project owner, meaning the Laos government, should pay special attention to the following points:

- Making the required decisions on time so as to improve communications and coordination with other construction parties (donors, consultants and contractors).
- Making efforts to modify and improve regulations, contracts and laws related to road projects to address the causes of delay shown to have a high severity index.
- Implementing annual programs for continuous training in cooperation with the contractor's union as a way to improve managerial skills, the checking and repair of equipment and vehicles, site engineering ability and labor skills.
- Resolving the problem of delayed payments to ensure that staged payments are made to contractors on time, since late payments affect a contractor's ability to finance the work. The result is time overruns and contracting companies may also use late payments as a reason to bargain with the Laos government (owner) in the case of delay.
- Allowing sufficient time to make adequate preparations for a project. This includes drawing up a planning schedule, particularly for the design phase to avoid the need for changes; detailed and comprehensive investigations of the site and site environment; and fully documenting all information before finally submitting the tender. This will help to avoid and later errors and thereby help avoid or minimize time and/or cost overruns.
- Re-checking the background, capabilities and resources of contracting companies before awarding the contract to the lowest bidder.

Contractors should consider the following:

- Ensuring the availability of sufficient resources in terms of budget, engineers, staff, laborers, equipment, vehicles and others that are necessary before bidding and making efforts to carry out projects at the specified time.
- Improving management of financial resources and cash flow by requesting staged payments.
- Ensuring that sufficiently skilled managers, engineers and staff are involved in the project.
- Providing expert training for laborers in relevant work practices so as to improve skills before beginning work, especially in the case of large projects or high-risk workplaces.
- Taking responsibility for the specified quality, cost and schedule.
- Improving communications and coordination with other construction parties (donors, owners, consultants and others) so as to obtain good results.

Consultants should look to the following:

- Providing all necessary information and documentation for the road construction project to other construction parties and, if possible, preparing sample documents and a recommended timeline for document processing.

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- Providing owners and contractors with payment documents in a more timely way, because the severity index of "contractor revolving money" and "owner payment is postponing" are the top of causes of delays in road construction projects.

VI. Conclusion

In this study, the causes of these delays are elucidated through a questionnaire survey, with the severity of each cause obtained from the viewpoints of contractors, owners and consultants. The 53 possible causes of delay included in the questionnaire were obtained through a detailed literature review and in consultation with expert civil engineers in Laos. The identified causes are combined into eight groups: project, owner, contractor, consultant, design, laborers, materials and equipment and external. The questionnaire was completed by 35 contractors, 31 owners and 24 consultants.

The top five causes of delay by severity index in the ranking obtained from the results are the following:

- Contractor cash flow;
- Delayed payment by owner;
- Difficulties in financing project by contractor;
- Financial issues related to owner; and
- Insufficient equipment and vehicles for the work.

The Spearman rank correlation showed that there is relatively good overall agreement between contractors and owners (rs = +0.474), contractors and consultants (rs = +0.465) and especially between owners and consultants (rs = +0.831) as to the severity rank of delay causes.

Further analysis of the data obtained from the questionnaire showed the following:

- There are no causes of delay with a severity index less than 20%;
- Severity indexes from the contractors' viewpoint are considerably higher than from the owners' and consultants' viewpoint. There are no causes with a severity index of less than 40% from the contractors' viewpoint; and
- The group severity index from the combined viewpoint ranges between 46.22% and 60.94%. This indicates that all the identified causes are highly relevant to the problem of delays in road construction projects in Laos.

The results of this study suggest that a necessary future task is to use the severity index of delay causes as a baseline for improving rules, agreements, management, administration and planning. The modified processes should be tested and used, then checked against percentage delays to determine if there has been any improvement. This process should be iterated to make the project implementation process as good as possible.

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Evaluation of Seismic Performance Focusing on Increasing Response of Lead Rubber Bearing (LRB) and Over Strength of RC Pier During Earthquake

By Naito Nobuyuki, Park Kyeonghoon, Mazda Taiji, Uno Hiroshige & Kawakami Masahide

Kyushu University

Abstract- The characteristics of the seismic bearing change depending on various factors. When an earthquake occurs, the behavior of the bridge may differ from the values expected in the structural design. The shear deformation of the seismic bearing may increase, but it is difficult to reach the fracture deformation. This paper studied the effect of the stiffness due to various dependency and durability on Lead Rubber Bearings (LRB) and the over strength of bridge piers on the bearing behavior when an earthquake occurred. As a result, if the stiffness of LRB reduces within the criteria, seismic performance can be expected safety even if the shear strain designed in the current design is greater than the allowable shear strain. The reason is that the hardening phenomenon in the high strain region of the laminated rubber bearing suppresses the displacement. Also, since the seismic bridges with over strength of the piers have come near elastic behavior when an earthquake occurs, shear strain is easy to be large.

Keywords: rubber bearing characteristic change, hardening, lead rubber bearing, pier ductility, non-linear time history analysis, over pier strength.

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Evaluation of Seismic Performance Focusing on Increasing Response of Lead Rubber Bearing (LRB) and Over Strength of RC Pier During Earthquake

Naito Nobuyuki [α], Park Kyeonghoon [σ], Mazda Taiji [ρ], Uno Hiroshige [Ѡ] & Kawakami Masahide [¥]

Abstract- The characteristics of the seismic bearing change depending on various factors. When an earthquake occurs, the behavior of the bridge may differ from the values expected in the structural design. The shear deformation of the seismic bearing may increase, but it is difficult to reach the fracture deformation. This paper studied the effect of the stiffness due to various dependency and durability on Lead Rubber Bearings (LRB) and the over strength of bridge piers on the bearing behavior when an earthquake occurred. As a result, if the stiffness of LRB reduces within the criteria, seismic performance can be expected safety even if the shear strain designed in the current design is greater than the allowable shear strain. The reason is that the hardening phenomenon in the high strain region of the laminated rubber bearing suppresses the displacement. Also, since the seismic bridges with over strength of the piers have come near elastic behavior when an earthquake occurs, shear strain is easy to be large.

Keywords: rubber bearing characteristic change, hardening, lead rubber bearing, pier ductility, non-linear time history analysis, over pier strength.

I. Introduction

The factors for changing the response of LRB are shown in Tab. 1. The properties of LRB vary by several factors. The actual behavior of earthquakes may be different from the expected behavior of the structural design [1]. In Tab. 1, the length of the arrow indicates the change in response. The earthquake reduces the stiffness of laminated rubber bearings and causes large shear deformation. Eventually, fracture deformation occurs beyond the allowable shear deformation [2]. However, since the hardening occurs in the high shear deformation region of the laminated rubber bearing, the resistance force is greater than when it is designed without hardening [3]. The actual displacement of the laminated rubber bearing of the structure is suppressed than the designed displacement, and it has a result that it is difficult to reach the fracture deformation. Besides, the pier has over strength, and the yield load becomes larger than the expected design. Therefore, the resistance of the pier during an earthquake is strengthened, but a large inertia force acts on the laminated rubber bearing. Moreover, a factor that increases the shear deformation of the laminated rubber bearing during an earthquake is involved statically indeterminate force due to the expansion and contraction of the girder caused by temperature changes. This paper proposes that the elongation of girders caused by expansion and contraction cannot ignore the effects of statically indeterminate force on seismic performance [4, 5]. Also, the temperature dependency of the laminated rubber bearing at low temperatures is large [6, 7]. In continuous girder bridges, the performance of laminated rubber bearings installed in each pier differs from the design values by dispersion of inertia forces, and the inertia forces acting on specific bearings, and substructures change. For this reason, it is preferred that the laminated rubber bearing applied to the continuous girder bridges is manufactured in the same manufacturing process as possible so that there is little difference in performance among products [8]. On the other hand, because the ground conditions are different from the design expectations, there is a possibility that the seismic performance of the bridge may be lost due to changes in the characteristics of the foundation. This paper focuses on bridges with LRB that increase shear strain during an earthquake, and various cases were analyzed for this examination bridge. The details can be divided into the effect of reducing the deformation of hardening due to the stiffness reduction of LRB during an earthquake, the effect of over strength RC column type pier on the response of LRB and the effect of LRB stiffness increase or decrease in continuous girder bridge. Besides, temperature change, which is a factor in which shear strain of LRB increases, has already been shown in past papers [4, 5]. Also, since the quantified amount of change in the foundation is uncertain and the impact of the change in the condition of the foundation is not expected to be significant when the pier is plasticized, it is not considered in this paper.

Author α: Dr. Eng., ARK Information Systems, INC., Tokyo, Japan. e-mail: Naito.nobuyuki@ark-info-sys.co.jp
Author σ: Graduate student, Department of Civil Engineering, Kyushu University, Fukuoka, Japan. e-mail: khoon1103@gmail.com
Author ρ: Dr. Eng., Full Professor, Department of Civil Engineering, Kyushu University, Fukuoka, Japan. e-mail: mazda@doc.kyushu-u.ac.jp
Author Ѡ: Dr. Eng., Professional Engineer, Ichii Consultant Co., Ltd., Japan. e-mail: huno@oak.ocn.ne.jp
Author ¥: Dr. Eng., CEO, Structural Engineering Research Institute for Disaster Prevention L.L.C, Fukuoka, Japan. e-mail: masahide09210715@hotmail.co.jp

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Table 1: Factor for variation of response for LRB

Factor for variation of response		Contents of factor	Response of LRB Less Much	Note
Durability	Compressive fatigue durability	Ability variation by fatigue durability due to repeatedly compression		Evaluation by NEXCO
	Shear fatigue durability	Ability variation by fatigue durability due to repeatedly shear force		
Stability	Periodic dependency	Ability variation depending on input period of seismic force		
	Temperature dependency	Ability variation due to ambient temperature		
	Bearing dependency	Ability variation due to pressure under vertical load		
Hardening		Characteristic of rubber by hardening in high strain region		Constantly appearance
Overstrength of pier		Enhancement of yielding stiffness and yielding load of pier due to execution, aging etc.		
Non-static stability force due to temperature change		Influence to initial load during earthquake due to non - static stability force		
Aging deterioration of rubber		Hardening of rubber by aging		
Allotment of inertia force on continuous girder		Variation of distribution of inertia force caused by bearing, substructure etc.		
Characteristics of foundation ground		Ground property exceeding assumptions		

Table 2: Coefficient on calculation of Cr (γ) for LRB

Application condition		a_0	a_1	a_2
$\gamma \leqq 1.75$	Common	1	-	-
$1.75 < \gamma \leqq 2.50$	G8	0.905	0.028	0.015
	G10	1.046	-0.161	0.077
	G12	1.049	-0.203	0.100

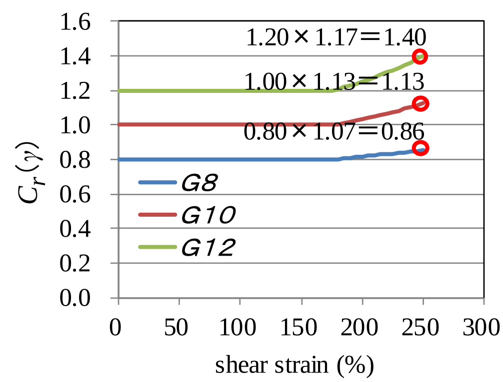

Fig. 1: Cr (γ) for LRB

II. Consideration of Factors for Analysis

a) Decrease the stiffness of LRB

In a bridge equipped with laminated rubber bearings such as isolating bearing, there is a possibility that stiffness may be reduced due to the performance differences, dependency, and durability for each product [9, 10]. As a result, the strain of laminated rubber bearings during an earthquake is larger than expected in structural design. The East, Central, and West Nippon Expressway Co., Ltd. defined the limit value of the performance variation due to these factors as R_{k+} and R_{k-}, and sets limits of +0.30 and -0.15 respectively [11].This value was based on the Standard Specifications for Structure Construction Management (Jul.2012) and was calculated using the formula in Appendix 1. This paper studied the case where the shear modulus of LRB decreased by 15% as the maximum value and increased by 30% as the minimum value of the expected stiffness in LRB. In the model of piers that assumed continuous girder bridges, the effect of dispersion was also analyzed by combining the case where the stiffness of LRB between piers was increased by 30% and the rigidity of LRB was decreased by 15%.

b) Hardening of LRB

The equivalent shear modulus of elasticity $G(\gamma)$ for shear cross-sectional deformation in consideration of hardening of LRB by Takahashi et al. is shown in equation (1) [12].The first term $C_r(\gamma)$ in Eq. (1) includes the effect of stiffness increase due to hardening given in Tab. 2. Fig. 1. shows the relationship between $C_r(\gamma)$ and shear strain. The $C_r(\gamma)$ of LRB, G12 in this paper, becomes 1.17 at 250% of shear strain.The second term used $q(\gamma)$ in the Manual for Highway Bridges Bearings [2].

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Table 3: Change of characteristic based on experiences of over strength for pier

Variation factor	Variation rule	Average	Variation coefficient	Average - σ	Average + σ
Yielding rigidity	$K_{PY}^{R}=(1\pm S)\cdot AVE(K_{PY})\cdot K_{PY}^{0}$	0.96	0.14	0.83	1.09
Yielding load	$P_{PY}^{R}=(1\pm S)\cdot AVE(P_{PY})\cdot P_{PY}^{0}$	1.14	0.06	1.07	1.21
□^{R}:Stochastic quantity under dispersion, S：Coefficient of variation, AVE：Average of dispersion □^{0}: Designed value, PY: Time on yielding of pier,σ: Standard deviation					

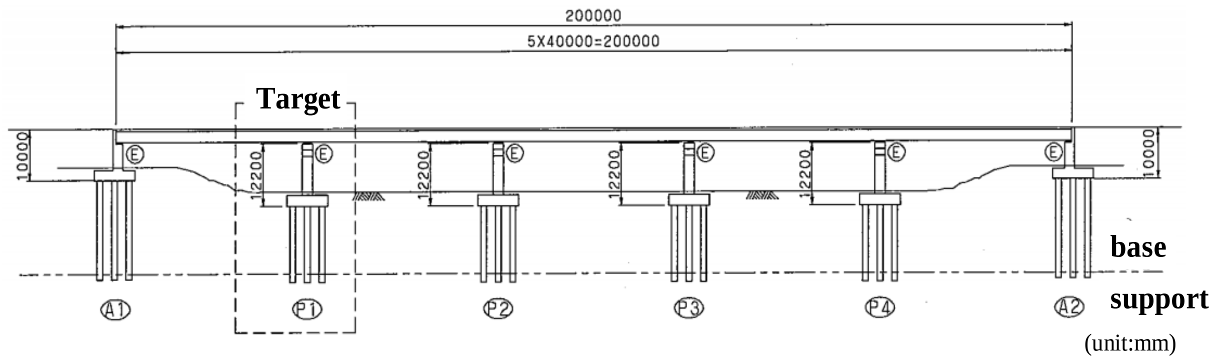

Fig. 2: General side view of examination bridge

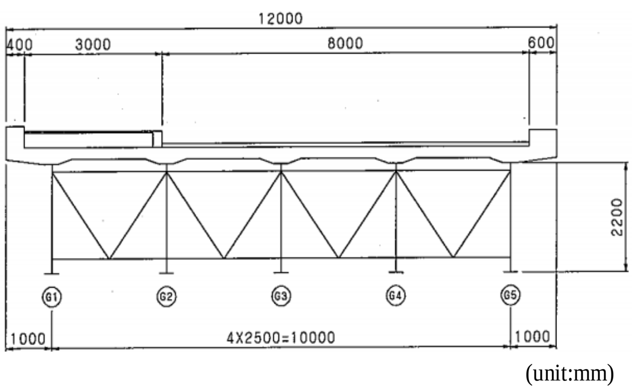

Fig. 3: Cross section of superstructure for examination bridge

Table 4: Sectional component of pier

Column height(m)			10.0
Column width(m)			5.0
Column thickness(m)			2.2
Material of reinforcement	main		SD345
	hoop		SD345
Longitudinal reinforcement		L	D38ctc125-2.0 step
		T	D38ctc125-1.0 step
Transverse restriction reinforcement		L	D16ctc150, L=750
		T	D16ctc150, L=880
Reinforcement for shear force		L	D16-8, 150pitch
		T	D16-5, 150pitch

$$G(\gamma)=C_r(\gamma)G_e+q(\gamma)\frac{\kappa}{\gamma} \quad (1)$$

Where,
$C_r(\gamma)$: Strain dependency coefficient
G_e: Shear modulus of rubber (N/mm^2)
$q(\gamma)$: Shear stress of lead plug (N/mm^2)
κ: Area of lead plug / Area of rubber bearing

c) Over strength of the pier

The performance variation due to the over strength of the piers proposed by Adachi and Unjou et al. is shown in Tab. 3 [13].This table shows the yield stiffness of the pier, the average value of the yield load, and the coefficient of variation. Here, the over strength range was set to three cases: average$-\sigma$, average, and average$+\sigma$, which has a relatively high incidence.In addition, the maximum, average and minimum values of yield stiffness and yield load occur at the same time, respectively.

III. Bridge to be Reviewed

The bridge to be reviewed is located on the Type II ground listed in the Reference Design Calculation Examples of Seismic Design for Highway Bridges [14]. Fig. 2 and 3 show five spans continuous non-composite steel girder bridge. Fig. 4 shows the cross-section of the pier. This bridge is equipped with distributed rubber bearings (RB). This research replaces the bearing of the pier from RB to LRB. The cross-sectional configuration of the pier was set by adjusting only the arrangement of the bar without changing the dimensions of the cross-section of the pier. The maximum shear strain of LRB is designed to 250%, the

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allowable shear strain. Tab. 4 and 5 show the cross-section configuration of the pier and LRB. Also, Fig. 5 shows the historical model of the pier. Tab. 6 shows the maximum shear strain of LRB and the maximum ductility factor of the pier.

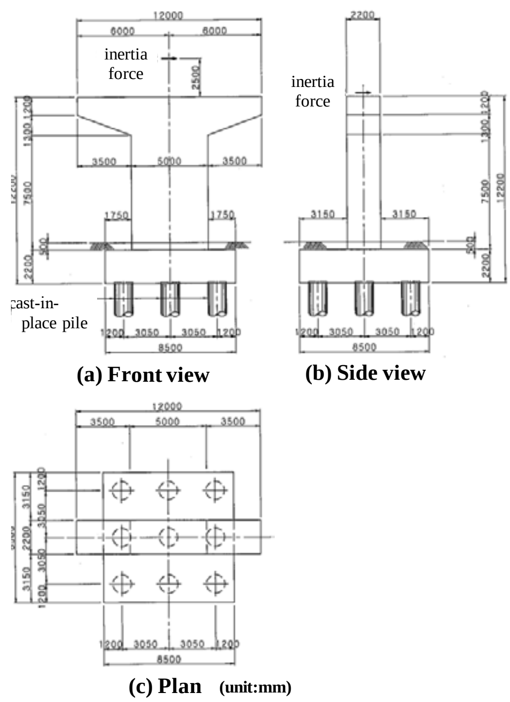

Fig. 4: Structural general view of pier

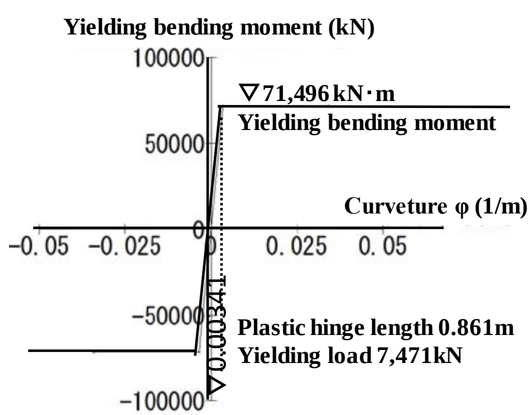

Fig. 5: Hysteresis model of pier base

Table 5: Sectional component and performance of LRB (/unit)

Item	Unit	Value
Usable dimension (bridge axial direction)	mm	735
Usable dimension (bridge perpendicular direction)	mm	735
Monostromatic thickness	mm	32
Number of layers	Sheet	4
Total thickness of rubber	mm	128
Elastic shear modulus of rubber	N/mm2	1.2
Diameter of lead plug	mm	106
Number of lead plugs	number	4
The first shape factor	-	5.367
The second shape factor	-	5.742
Modulus of longitudinal elasticity	N/mm2	290
Effective area	mm2	504926
Area of lead plugs	mm2	35299
Occupation ratio of lead plugs	-	0.070
Yielding load	kN	294.3
Shear spring constant (horizontal rigidity)	kN/m	4734
Pressure spring constant (vertical rigidity)	kN/m	1143252
Shear stress of lead plug	N/mm2	2.0
Design displacement	Mm	320
Design strain	%	250
Horizontal force	kN	1584
First rigidity	kN/m	26198
Second rigidity	kN/m	4030
Equivalent rigidity	kN/m	4950
Equivalent damping coefficient	-	0.113

Table 6: Maximum response of pier and LRB

Input seismic wave		LRB maximum shear strain (%)	Pier maximum ductility factor
Type I	I-II-1	128	0.700
	I-II-2	119	0.714
	I-II-3	110	0.710
	Average	119	0.708
Type II	I-II-1	241	1.428
	I-II-2	215	1.179
	I-II-3	289	1.448
	Average	248	1.351
Allowable		250%(320mm)	1.695(0.0449m)

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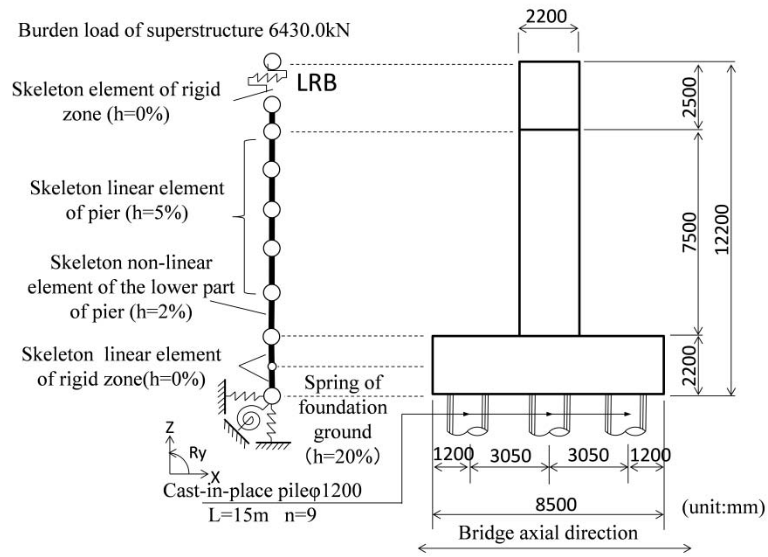

Fig. 6: Analytical model

Table 7: Table of hysteresis model

Application	High strain region	Hysteresis shape	Setting of shear modulus of rigidity (N/mm2)	Resistance force on 250%(kN)	Abbreviation	
Handbook of bearing	Linear	Bilinear model	1.2	1,584	H-Li-Bi-1.0	H: handbook L: literature Li: linear HD: hardening Bi: bilinear Tri: trilinear 1.0: non-rigid reduction 0.85: rigid reduction-15%
			1.2×0.85=1.02	1,357	H-Li-Bi-0.85	
Conformity to handbook of bearing※	Hardening		1.2×1.17=1.404	1,842	H-HD-Bi-1.0	
			1.2×0.85×1.17=1.1934	1,576	H-HD-Bi-0.85	
		Trilinear model	1.2×1.17=1.404	1,842	H-HD-Tri-1.0	
			1.2×0.85×1.17=1.1934	1,576	H-HD-Tri-0.85	
Literature		Bilinear model	1.2×1.17=1.404	1,836	L-HD-Bi-1.0	
			1.2×0.85x1.17=1.1934	1,571	L-HD-Bi-0.85	

※Conformity means including hardening behavior for handbook

IV. Review Conditions

In this paper, the purpose of this research is to understand the effect of LRB stiffness reduction on single pillar pier upporting superstructure and the effect for dispersion of inertia force by combined decrease and increase of LRB stiffness on multi-pier during an earthquake. For reference, column type piers and wall type piers are representative types of piers. In this research, the column type pier is used as an analysis model. Fig. 6 shows the structural model for the analysis. This structural model is the single pillar supporting beam of the bridge under review in Fig. 2. The analysis method is a nonlinear time historical response analysis. The input seismic waves were three waves of each Type I and Type II seismic wave in the Design Specifications for Highway Bridges part 5, Seismic Design and evaluated by the average of the responses from the three different waves [1].

V. Effect of Hysteresis Characteristics by Reducing the Stiffness of LRB

a) *Conditions of LRB hysteresis*

The analysis that applies the history set in manual for Highway Bridges Bearings to the hysteresis characteristic of LRB is called the current design. The stiffness, which was decreased by 15% of LRB, was designed to 0.85 times the shear modulus of the rubber. The resistance force of the laminated rubber of G12 increased by hardening is 1.2 × 1.17 = 1.40 N/mm^2 calculated in Fig. 1 with a shear strain of 250%. The bilinear and trilinear models are typical models considering the hardening of laminated rubber bearings. The bilinear model has a history that LRB behaves as a secondary stiffness concerning a working load equal to or higher than the yield load in the same way as the current design. The trilinear model assumes that the

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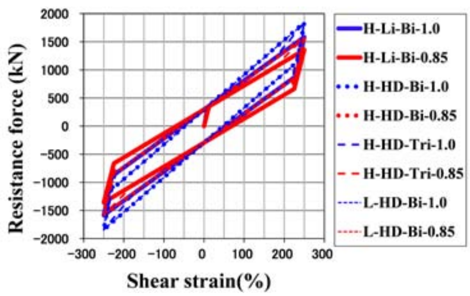
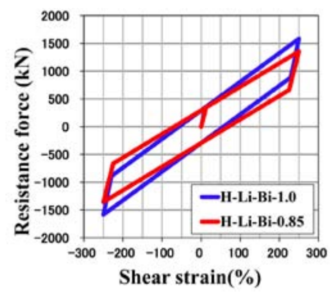
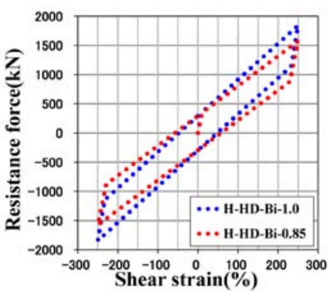
hardening occurs when the shear strain of the bilinear model is 175% or more, and the resistance is a history that increases linearly with respect to the shear strain. Also, comparison by analysis using the setting formula of LRB proposed by Takahashi et al. was also conducted [12]. The Tab. 7 shows the combinations used for the review. The hysteresis characteristics of the laminated rubber and lead plugs, which are the results obtained from the analysis, are superimposed and shown in Fig. 2. That is, in the region where the deformation is small, the hysteresis of the lead plug is the main.After the lead plug yields, the resistance force increases linearly due to the shear elasticity of the laminated rubber. These hysteresis characteristics were designed in the form of bilinear or trilinear. Fig. 7 shows a comparison of the history of LRB used in the analysis. The maximum shear strain was set at 250%. Convergence analysis using the hysteresis of the maximum shear strain obtained in the analysis is not performed. (a) shows all the cases and (b), (c), (d), (e) show the case where there is no stiffness drop for each hysteresis characteristic and the case where the stiffness decreases by 15%, respectively.



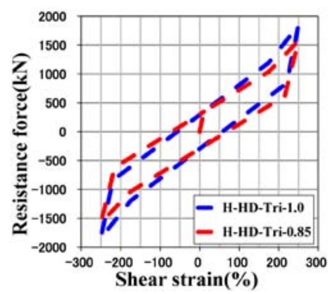
(a) All hysteresis mode



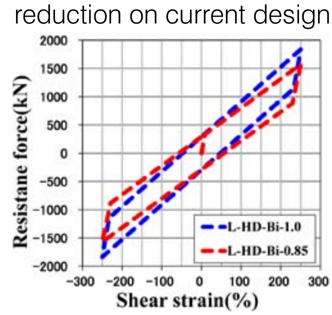
(b)-15%Li-Bi and 15% rigid reduction on current design



(c) HD-Bi and 15% rigid reduction on current design



(d) HD-Tri and 15% rigid reduction on current design



(e) L-HD-Tri and 15% rigid reduction on literature design

Fig. 7: Comparison of hysteresis models

b) Analysis results

Fig. 8 shows the maximum shear strain of LRB and the maximum ductility factor of the pier due to the difference in stiffness and hysteresis of LRB. Fig. 9 and Fig. 10 show the response history of LRB and the lower part of the pier by seismic waves II-II-1, respectively.

c) Effect of the hardening on current design

The maximum shear strain of LRB, the response history of LRB, and the response history of the lower part of the pier are shown in Fig. 11. To understand the effects of hardening, a bilinear model and a trilinear model considering current design and hardening design were applied. When the analysis is performed using a bilinear model in consideration of the hardening, the maximum shear strain is reduced to 200%. In contrast, when analyzed using a trilinear model, it is as small as 230%, which is larger than the bilinear model and smaller than the current design. In the response history, the resistance force of LRB is large in the order of current design, hardening of the bilinear model, and hardening of the trilinear model. Likewise, the curvature of the lower part of the pier shows the same order.

d) Effect of the hardening on the current design and 15% decrease in stiffness

The cases where the stiffness is reduced by 15%, current design, the maximum shear strain of LRB, the hysteresis of LRB response, and the response of the lower part of the pier in consideration of hardening are shown in Fig. 12. In the current design, the maximum shear strain of LRB is 250%, but when the stiffness decreases by 15%, the maximum shear strain may increase to 300%, resulting in fracture deformation. However, because the shear strain of LRB is suppressed by hardening, the maximum shear strain in the bilinear model is 250%, which is equivalent to the current design. In contrast, in the trilinear model, the

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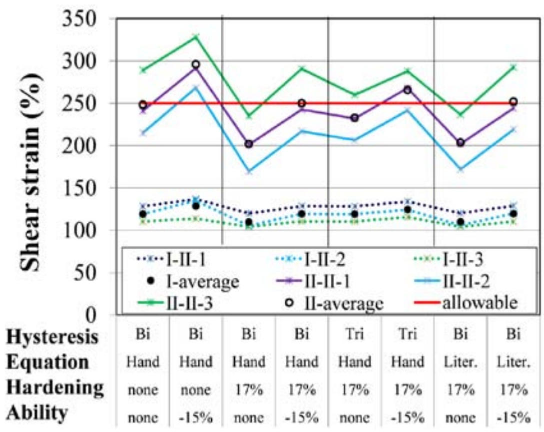
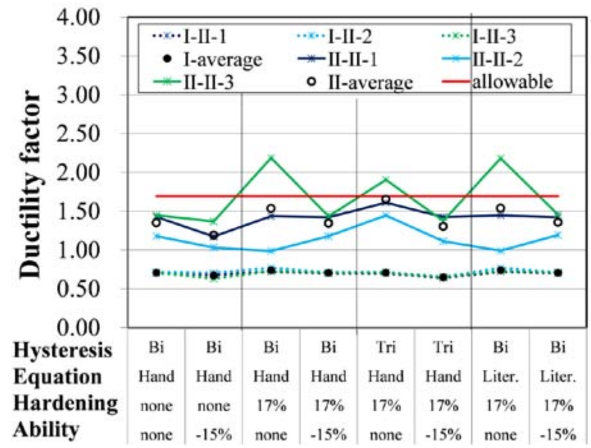
maximum shear strain is 270%, which is larger than the current design. Therefore, in actual design, it is necessary to consider the effect of the difference in the modeling of the hardening on the response.



(a) Maximum shear strain of LRB



(b) Maximum ductility ratio of pier

Fig. 8: Response by rigid reduction and hysteresis model of LRB

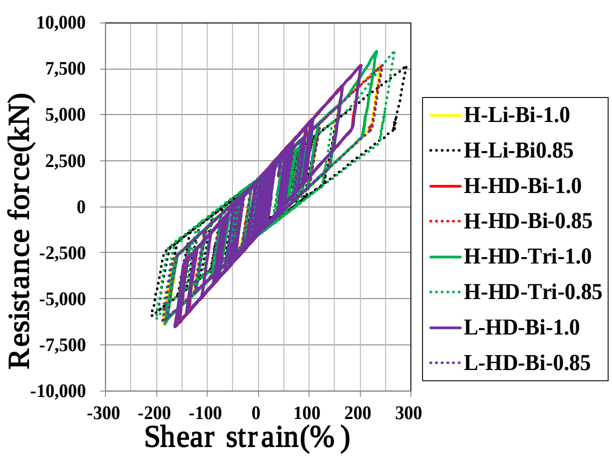


Fig. 9: Response hysteresis of LRB (II-II-1)

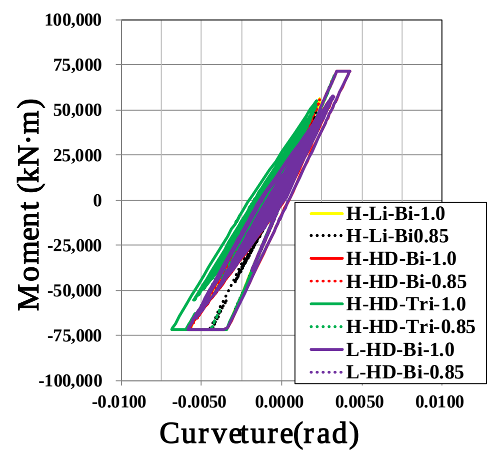
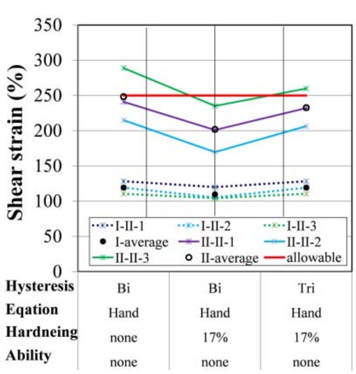
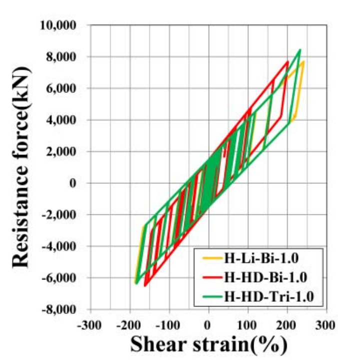


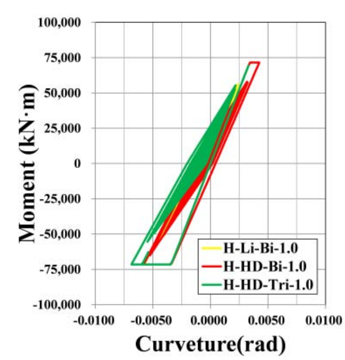
Fig. 10: Response hysteresis of pier base (II-II-1)



(a)Maximum shear strain of LRB



(b)Response strain hysteresis on LRB



(c)Response curvature hysteresis on LRB

Fig. 11: Effect of hardening on current design

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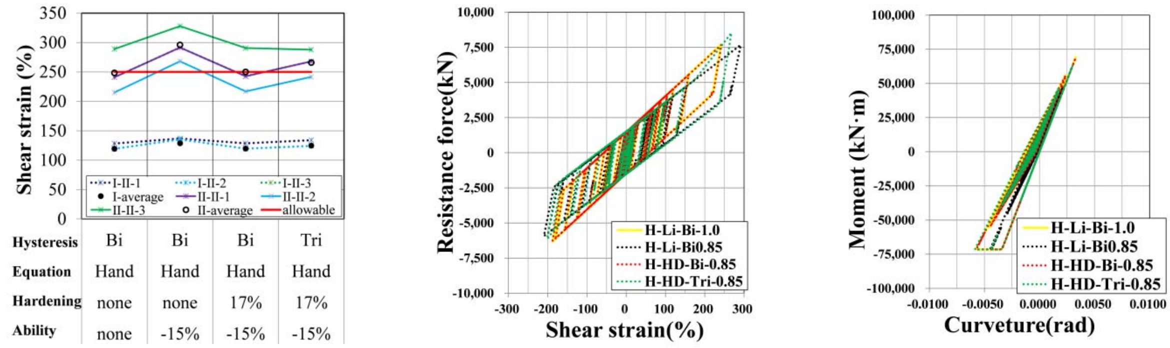
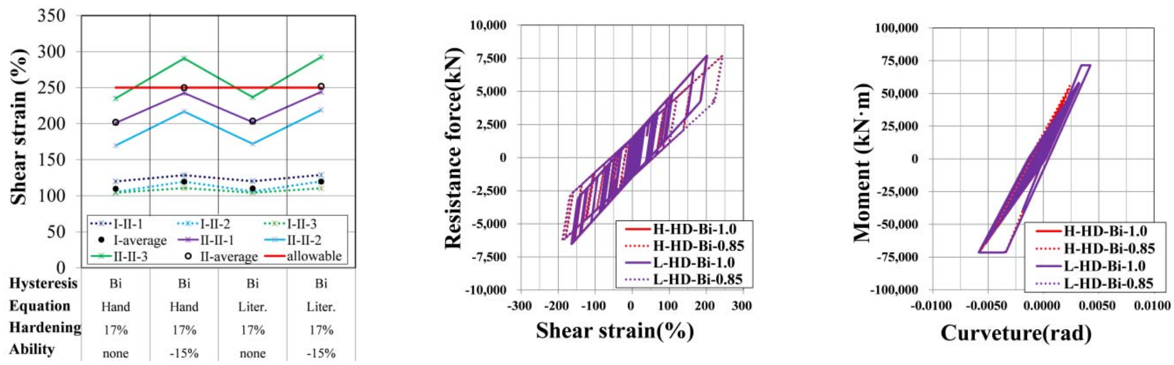


(a)Maximum shear strain of LRB

(b)Response strain hysteresis on LRB

(c)Response curvature hysteresis on LRB

Fig. 12: Effect of hardening on current design and 15% stiffness rigid reduction



(a) Maximum shear strain of LRB

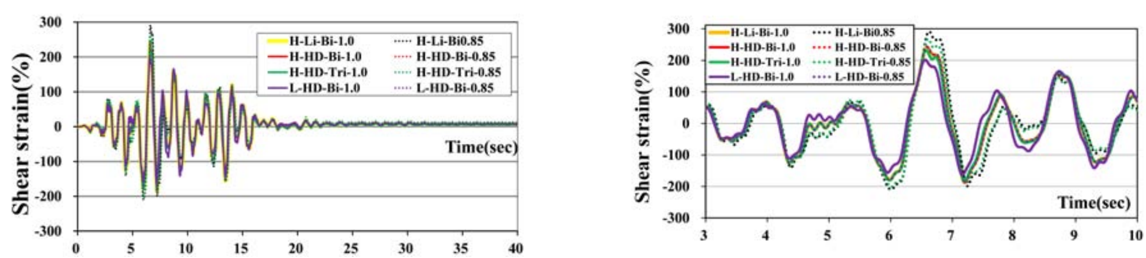
(b) Response strain hysteresis on LRB

(c) Response curvature hysteresis on LRB

Fig. 13: Effect of hardening and literature model on current design

e) Comparison of the response on hardening model and current design

The comparison of the hardening model and the response of the current design is shown in Fig. 13(a). Fig. 13(b) and (c) show the maximum shear strain of LRB, response history of LRB, and response history of the lower part of the pier when stiffness drop occurs by 15%. The maximum shear strain of LRB is 250% in the current design and 300% when the stiffness is reduced by 15%. In this paper, the maximum shear strain and LRB response history are the same as those of the current design, but the curvature history of the lower part of the pier is slightly different. This is because the rubber dependence coefficient $C_r(\gamma)$ applied in the process of setting the hardening of the current design is equal to the value set in this paper. However, since the coefficient $q(\gamma)$ for the lead plugs in the current design uses the values given in Manual for Highway Bridges Bearings, it is considered that the response of this paper and the current design may differ depending on the lead area ratio setting of LRB.



(a) From 0 to 40 seconds

(b) From 3 to 10 seconds

Fig. 14: Shear strain responsive wave of LRB (II-II-1)

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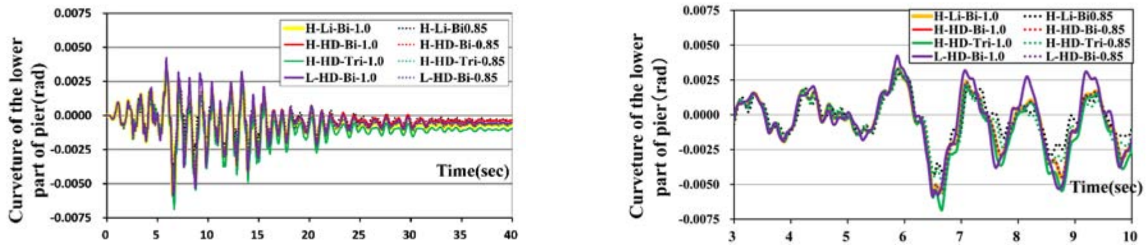
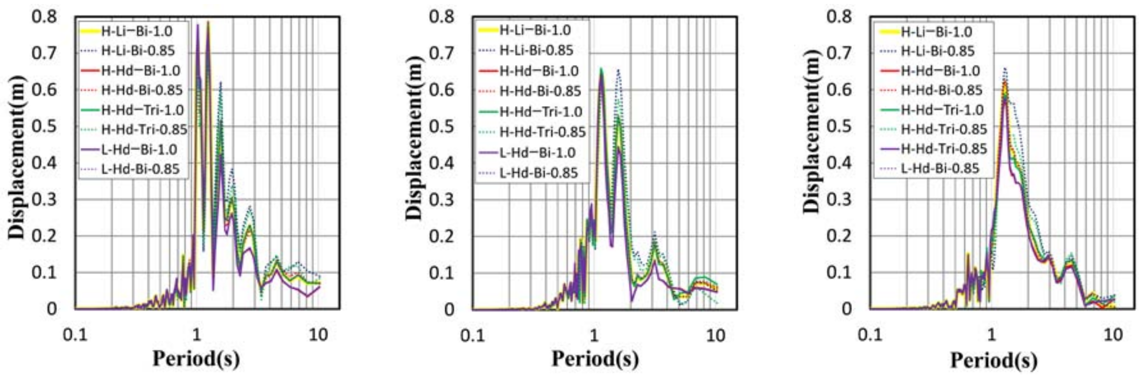


(a)From 0 to 40 seconds

(b)From 3 to 10 seconds

Fig. 15: Curvature responsive wave of pier base (II-II-1)



(a)II-II-1

(b)II-II-2

(c)II-II-3

Fig. 16: Fourier spectrum responsive displacement of superstructure

f) Time history response waveform and period characteristics

Fig. 14 and 15 show the time history response waveforms of shear strain in LRB and curvature of the lower part of the pier when II-II-1 seismic waves are input. Fig. 14(b) enlarges the response of the main behavior, 3 to 10 seconds. The response waveform for each LRB history shape is almost the same regardless of the history shape. However, the difference in the maximum response value is shown around 6.5 seconds. When the stiffness decreased by 15%, it was confirmed that the shear deformation of LRB was larger, and the response period was longer. The maximum shear strain of LRB decreases due to the effect of hardening, but when the hardening is represented by the trilinear model, the maximum yielding load of the pier becomes large. In addition, at 175% shear strain, the stiffness of the rubber changes rapidly in the trilinear model, but the shear strain of LRB is not large, and a slight change in curvature of the lower part of the pier can be seen. Fig. 16 shows the Fourier spectrum due to the displacement of the superstructure to determine the period. Each earthquake waves are predominant during the same period regardless of LRB recording characteristics and reduction in stiffness. In II-II-1, there are three predominant period ranges, in II-II-2, two predominant period ranges, and in II-II-3, a single period range is widely distributed. The reason why the predominant period range is different for each wave is due to the characteristics of the input wave and the nonlinearity of LRB and the pier. Fig. 17 shows the period with the maximum value of the Fourier spectrum in each predominant period region. In II-II-1 waves, the period is most predominant at approximately 1.241 seconds. On the contrary, the current design with the bilinear model, which is a model with hardening under constant stiffness, and in case there is a predominant as well at a shorter period of 1.024 seconds.In the II-II-2 wave, the predominant period appears at around 1.138 seconds, but in the current design that does not consider hardening at a stiffness drop of 15%, the predominant period appears at 1.575 seconds. In the II-II-3 wave, the period is mostly same predominant in all cases at 1.280 seconds. This predominant response period should be considered based on not only the difference in seismic waves but also the difference in hysteresis due to stiffness reduction or hardening.

g) The difference in response between the bilinear model and the trilinear model

Fig. 18(a) shows the comparison of the history of the bilinear model of LRB and the trilinear model. These models are nonlinear models considering the hardening phenomenon of LRB. The same resistance force was designed at 250% of shear strain, but the result of the response history by the same seismic wave is different. Fig. 18(b) and 18(c) show the response results of LRB (HD-Bi-1.0, HD-Tri-1.0) without stiffness drop and LRB (HD-Bi-0.85, HD-Tri-0.85) with stiffness drop by inputting seismic wave II-II-1. As a result, there

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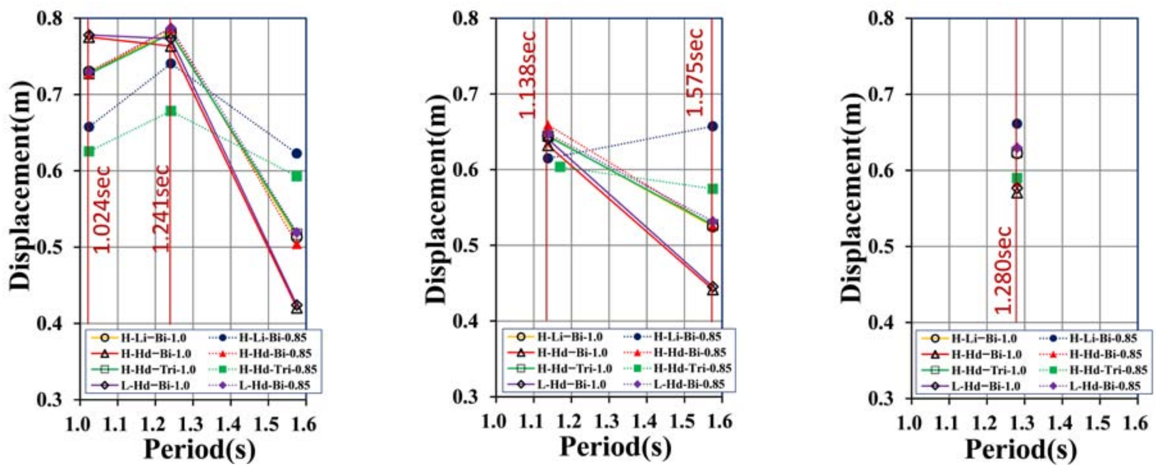
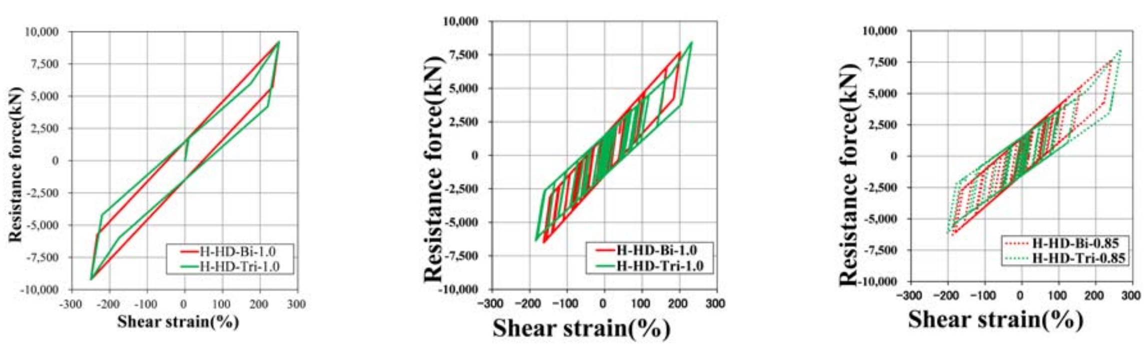
was a remarkable difference in the response history of LRB between the bilinear model and the trilinear model, and the trilinear model showed a larger shear strain than the bilinear model. This reason can be confirmed from each set history shown in Fig. 18. The resistance of LRB increases with increasing maximum shear strain. As shown in Fig. 18(b), when the maximum shear strain is less than 250%, the resistance force of the trilinear model is less than that of the bilinear model when the shear strain is the same. This means that with the same resistance force, the shear deformation of the trilinear model becomes larger than that of the bilinear model. The maximum shear strain of the hysteresis set in this analysis is 250%. Since this is different from the maximum shear strain in the results of the dynamic analysis, clearly the trilinear model cannot be a large response unless the maximum shear strain to determine the hysteresis converges. The maximum shear strain of the bilinear model is about 250% of the response history of LRB with reduced stiffness of 15% shown in Fig. 18(c). Since this shear strain is consistent with the value set in the analysis, there is no need to reset the hysteresis shape due to the maximum shear strain. On the contrary, since the response history of the trilinear model is larger than 250%, it is necessary to converge the history shape to the response history. At this point, the response of the trilinear model is larger than that of the bilinear model. Likewise, it can be seen that the response of the trilinear model is greater for the curvature of the lower part of the pier in Fig. 11.



(a)II-II-1 (b)II-II-2 (c)II-II-3

Fig. 17: Period at the time of maximum Fourier spectrum on predominant response



(a)Basic hysteresis on 250% (b)H-HD-Bi-1.0 and H-HD-Tri-1.0 (c)H-HD-Bi-0.85 and H-HD-Tri-0.85

Fig. 18: Basic hysteresis of bilinear model and trilinear model (250%, II-II-1)

h) Response waveform and predominant period

Tab. 8 shows the maximum values of displacement and resistance force at the time of maximum shear strain in Fig. 14. In addition, this table contains the equivalent damping ratio for the response history of the bilinear model and the trilinear model, and the correction factor for each equivalent damping ratio. The absorbed energy was calculated as the historic area of one cycle. Fig. 19 shows the energy absorbed by LRB during inputting the seismic wave. When calculating the equivalent damping constant, the strain energy was adjusted to an average value so that the starting point and the ending point could be one cycle. The absorbed energy is large in the trilinear model, but the equivalent damping constant is large in the bilinear model. The reason is that the resistance force and theelastic energy of the trilinear model are relatively larger than the bilinear model in the same shear strain.

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The correction factor for each equivalent damping constant is slightly larger in the bilinear model as 0.014.Still it does not indicate a difference in the decrease in response due to the damping performance.

Table 8: Hysteresis of bilinear model and trilinear model (II-II-1)

		Time	Displacement	Resistance force	Absorbed energy ⊿W	Equivalent damping constant, h	Correction factor based on damping constant, CD	Equivalent damping constant at 250%, h
		sec	m	kN	kN・m	%		%
H-HD-Bi-1.0	Time on minimum response just before maximum response	5.95	-0.199	-6,286				
	Time on maximum displacement	6.56	0.257	7,684	1,335.2	13.0	0.743	10.7
	Time on minimum response just after maximum response	7.16	-0.208	-6,502				
H-HD-Tri-1.0	Time on minimum response just before maximum response	5.98	-0.231	-6,211				
	Time on maximum displacement	6.57	0.297	8,436	1,508.1	12.1	0.757	10.2
	Time on minimum response just after maximum response	7.20	-0.235	-6,358				

i) *Consideration of LRB stiffness drop and response history in design*

The average of three seismic waves was evaluated in the current design. Depending on the seismic wave, there were some cases where the shear strain was greater than 250%. In particular, Fig. 11-(a) shows that the shear strain is about 290% in II-II-3 of the current design. This means that the shear strain of LRB exceeds 250% and approaches the fracture strain. On the contrary, when analyzed with a bilinear model considering hardening, the maximum shear strain among the three seismic waves is about 230%. Since it is within 250% of the allowable shear strain, the analysis results can be sufficiently reliable. Therefore, after analyzing the response of LRB in the current design, it is better to verify it using a bilinear model that considers the hardening and to confirm the fact that the shear strain of LRB is less than 250%. On the other hand, the trilinear model can be used to analyze the hardening phenomenon, but before that, it is necessary to verify the validity of the tertiary stiffness of LRB in the shear strain exceeding 250%.

VI. The Impact of over Strength of Pier on Response

a) *Setting of the pier*

To confirm the impact of the over strength of the pier on the response during an earthquake, a pier with a small plasticization with a maximum ductility factor of 1.351 (abbreviation as pier with $\mu = 1.351$) used in Tab. 6 and two piers with a ductility factor of 2.005 and 3.316 (abbreviation as pier with $\mu = 2.005$, $\mu = 3.316$) were added. Tab. 9 shows the conditions of these three piers and each set LRB. A pier with a high ductility factor was added to investigate the effect of plasticization due to over strength of piers on the behavior of LRB during an earthquake. The maximum ductility factor of the added pier does not satisfy the allowable ductility factor, but the purpose is to understand the effect of the high ductility factor due to over strength on the pier. In this paper, pier characteristics were determined based on the amount of change in over strength. The characteristics of the pier were divided into 4 cases: the 'standard value' without considering the over strength, the 'average value' with the over strength considered, and finally, the '$\pm\sigma$' considering the standard deviation. Also, the yield stiffness and yield load of the pier were set in the order of standard value, $-\sigma$, average value, and $+\sigma$. The ratio of yield load was set to 1.00: 1.07: 1.14: 1.21.

b) *Analysis result*

The maximum shear strain of LRB and the maximum ductility factor of the pier with seismic waves of level 2 seismic Type I and Type II are shown in Fig. 20. The horizontal axis represents the yield stiffness and yield load of each pier. In addition, even when the pier has an elastic response, the value obtained by dividing the maximum displacement of the pier by the yield displacement was defined as the ductility factor. The over strength is evaluated as the average of the responses by three seismic waves.

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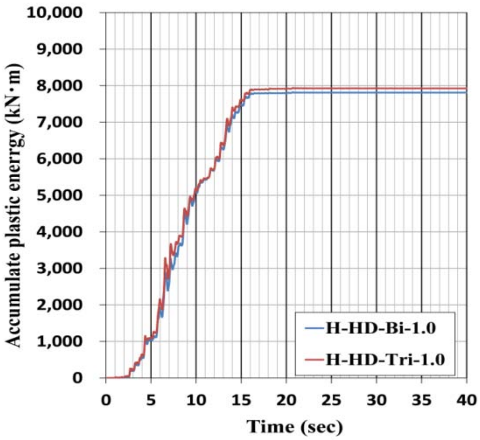
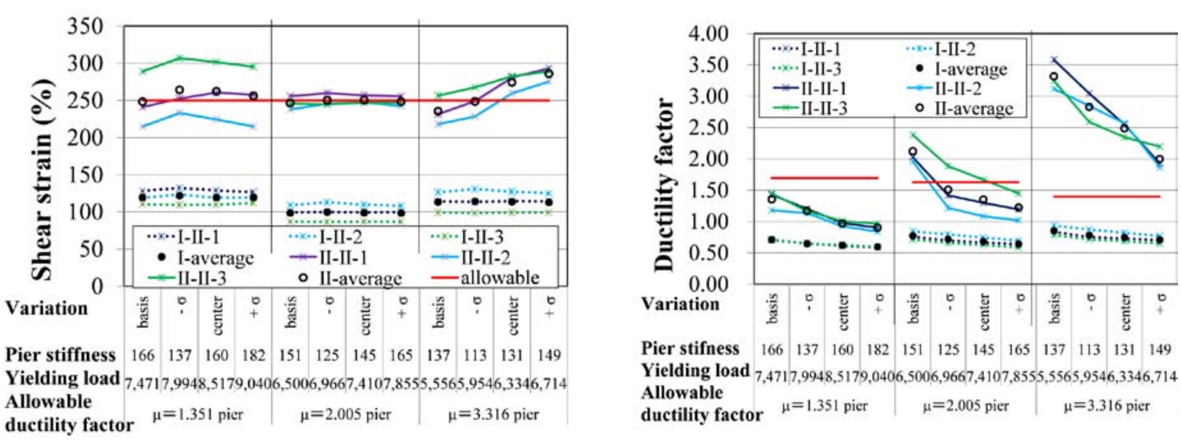


Fig. 19: Accumulate plastic energyon bilinear model and trilinear model (II-II-1)

Table 9: Pier for investigating over strength

		Basis pier	Middle ductility pier	Much ductility pier
Mass of superstructure (kN)		6430	6430	6430
Main reinforcement	Material	SD345	SD345	SD345
	Diameter	D38	D35	D32
Distance of transverse restriction		L750	L750	L1000
Configuration of LRB	Plane measure (mm)	□735	□700	□675
	Monostromatic thickness (mm)	32	25	19
	Number of layers	4	7	8
	Total thickness of rubber (mm)	128	175	152
	Occupancy of lead plugs (%)	7.0	6.9	7.1
	The first shape factor S1	5.37	6.55	8.29
	The second shape factor S2	5.74	4.00	4.44
Response of pier	Ductility factor	1.351	2.005	3.316
	Allowable ductility factor	1.695	1.628	1.395
LRB	shear strain (%)	248	246	253
	allowable shear strain (%)	250	250	250



(a) Maximum shear strain of LRB

(b) Maximum ductility ratio of pier

Fig. 20: Response including influence of over strength

c) *Effect on the maximum shear strain of LRB*

As shown in Fig. 20, since the pier behaves elastically in Type I, the pier yield load does not affect the maximum shear strain of LRB. However, because the yield stiffness and over strength are increasing at the same time, the maximum shear strain of LRB changes slightly. The following is a review of the response of Type II. In Fig. 20, in the pier with $\mu = 1.351$, the maximum shear strain of LRB increases as the yield load becomes $-\sigma$ to the standard value, but at the average value, $+\sigma$, the yield load increases and the shear strain decreases. In contrast, the $\mu = 2.005$ pier has an overall constant shear strain of LRB. Finally, for a pier with $\mu = 3.316$, the yield load and the maximum shear strain of LRB are proportional. In general, when the pier is plasticized, the maximum acting force of the rubber bearing becomes large, depending on the yield load of the pier. For this reason, the maximum shear strain of LRB of a pier with large plasticization and $\mu = 3.316$ is consistent with the general behavior. On the other hand, when the yield load of the pier increases, the maximum ductility factor of the pier necessarily decreases. As a result, the maximum ductility factor of pier with $\mu = 3.316$ at large plasticization decreases linearly due to the increase in the yield load of the pier. However, the trends of the pier

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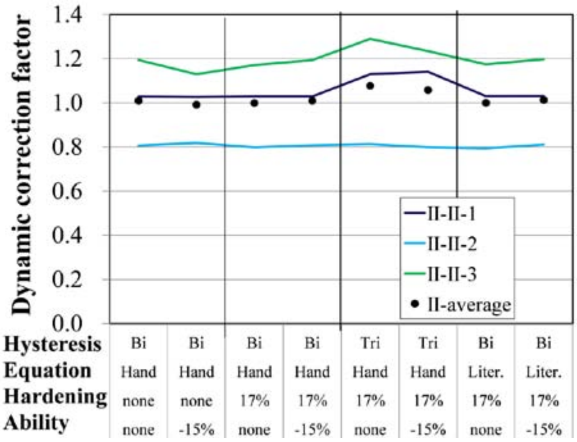
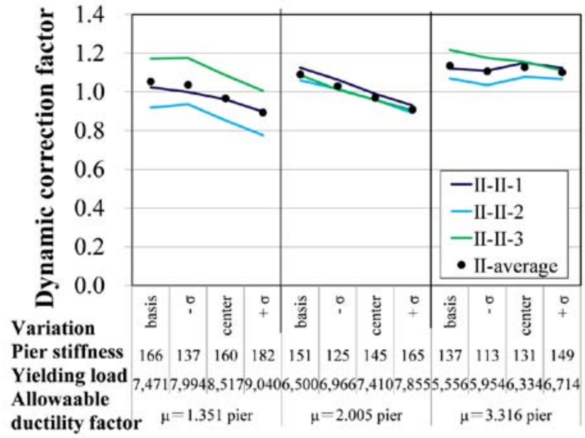
with $\mu = 1.351$and pier with $\mu = 2.005$ are different. The reason is that at the pier with $\mu = 1.351$, the average yield load and the maximum ductility factor of $+\sigma$are less than 1.0 and have the elastic response. That is, since the pier is not plasticized, the yield load of the pier does not directly affect the maximum shear strain of LRB. The pier with $\mu = 2.005$ is in a plasticized state due to over strength, but the maximum shear strain of LRB shows a different result from that of the pier with $\mu = 3.316$ because there is little change due to over strength.



(a) Response by rigid reduction and individual hysteresis of LRB



(b) Response including influence of over strength of pier

Fig. 21: Dynamic correction factor

d) Dynamic correction factor

The dynamic correction factor is calculated by dividing the maximum resistance force of LRB by the yield load of the pier. When the pier with $\mu = 3.316$in Fig. 21(b) is plasticized, the dynamic correction factor does not change significantly even if the yield load of the pier increases. In contrast, the dynamic correction factors for pier with $\mu = 1.351$ and $\mu = 2.005$ decrease with increasing yield load. In addition, when the yield load is the average value and $+\sigma$, the dynamic correction factor is less than 1.0, which means that LRB acting force is less than the yield load. In $\mu = 1.351$pier, the pier behaves elastically and $\mu = 2.005$ pier is plasticized, but the force acting on LRB is smaller than the yield load. For this reason, the increase in yield load did not significantly affect the maximum shear strain of LRB. This factor is considered to be caused by the inertia of the pier itself and the vibration mode of the second or higher order.

e) Evaluation of LRB for over strength

In the seismic isolation bridge, the plasticization of the lower part of the pier is suppressed. However, it was confirmed that the maximum shear strain of the bearing did not necessarily increase even if the yield load increased due to over strength. Since the specifications of the designed bridge are varied, the effects of over strength are different. Therefore, it is necessary to investigate the effect of over strength on the response for each bridge. Meanwhile, the dynamic correction factor in Fig. 21(a) is a vibration system using a pier with $\mu = 1.351$, and there is little change in the dynamic correction factor due to the elastic response of the seismic wave. On the contrary, when the hardening of LRB is analyzed with a trilinear model, the dynamic correction factor is increasing. This is because the force on the pier was increased by the trilinear model. As a result, it is larger than the case of applying the bilinear model.

f) Effect of over strength to the lower part of the pier

In general, the yield load of the lower part of the pier is designed to be more than 1.1 times the yield load of the pier, so that the lower part of the pier does not yield before the pier. However, if the yield load of the lower part of the pier is exceeded due to over strength, there is a concern that the lower part of the pier will yield first. Fig. 22 shows the relationship between the bending moment and the yield bending moment of the lower part of the pier considering the over strength of the pier. As a result, the bending moment of the lower part of the pier is difficult to increase and slightly exceeds 1.1 times the yield bending moment of the pier without the effect of over strength. Therefore, the maximum shear strain of LRB of the seismic isolation bridge, where plasticization of the pier is suppressed, is not affected by the over-strength, but it is necessary to consider the safety of the lower part of the pier separately.

VII. Influence of Dispersion in Multi-Span Girders

a) Pier model to be reviewed

The framework of the girders of the two single column bridge piers and four single pillar pier supporting superstructure, which are the models to be

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reviewed is shown in Fig.23. For this model, the effect of the stiffness change of LRB between piers on the load distribution was analyzed for each case. The specifications of the pier model are the same as those used in this paper. The stiffness of LRB was set by increasing or decreasing to 1.30 times and 0.85 times the maximum value of the design based on reference 11) and combined in Tab. 10 for each pier. The hysteresis shape was set as a bilinear model as shown in Fig. 24. Here, the cross-sectional area of the girders installed between piers is 0.6085m2 according to reference 14).

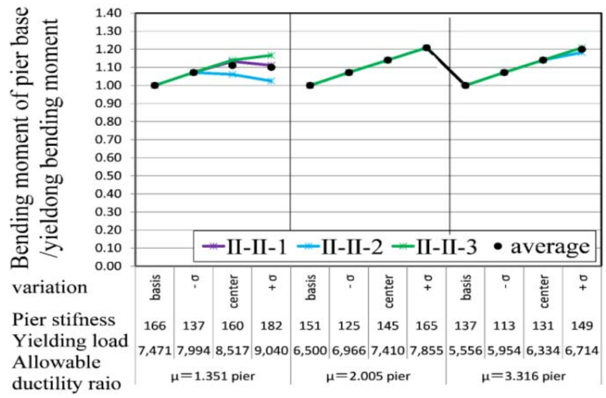
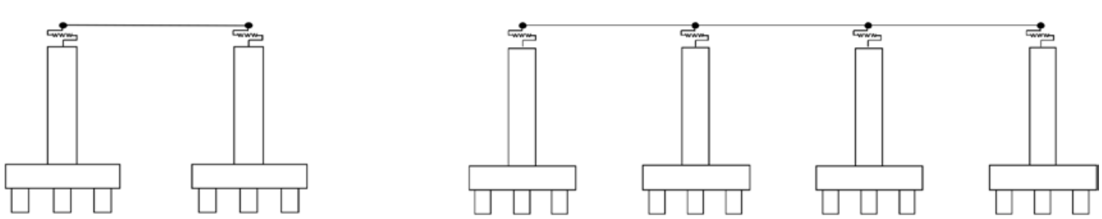


Fig. 22: Maximum bending moment of over strengthened pier with μ=1.351

b) *Effect of response history and dispersion between piers*

The response history of LRB and the history of the lower part of the pier are shown in Fig. 25 and Fig. 26. The shear strain of LRB of the 0.85 model (0.85) is larger than that of the 1.00 model (1.00) without stiffness change and smaller than that of the 1.30 model (1.30). However, the shear strain of 0.85 does not increase in the case where the 1.30 model increases from the four pier models to three. This is considered to be because the inertia force of the superstructure is concentrated at 1.30. On the other hand, the response of the lower part of the pier is largely plasticized in the 1.30, but plasticization hardly occurs in the 0.85. In particular, in the case of one 1.30 among the four pier models, an extremely large plasticization occurs because most of the inertia force of the superstructure is concentrated only in this pier. However, the response change of LRB is not much different compared to the plasticization of the lower part of the pier. This means that it is difficult to concentrate the load on LRB due to the plasticization of the pier, but the seismic energy is largely consumed as the plasticization of the lower part of the pier proceeds. The time history response resistance waveform of LRB and the time history response curvature at the lower part of the pier are shown in Fig. 27 and 28. In the time history response waveform, there is no significant difference in the resistance waveform of each model's LRB. In contrast, the curvature of the time history response at the lower part of the pier varies greatly for each pier. Particularly, when the residual variation at the 1.30 pier is large and there is only one 1.30 model, quite large residual variation occurs. The comparison of the shear strain of LRB, the bending moment of the lower part of the pier, and the ductility factor of the lower part of the pier between models are shown in Fig. 29, Fig. 30 and Fig. 31, respectively. From this, it can be seen that when the rigidity of the 1.30 model and LRB is increased, the response of LRB decreases, but on the contrary, the plasticization of the lower part of the pier becomes large. In conclusion, if there is a difference in the performance of LRB for each pier, it gives a significant effect in the plasticization of LRB and the lower part of the pier, and has a greater effect on the pier. Although the results of this research are extreme cases, it is desirable to make LRB installed at each pier in the same manufacturing process as much as possible so that there is no difference in performance of LRB.



(a) 2 piers model (b) 4 piers model

Fig. 23: Dispersion effect review model of multi span girder

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Table 10: Stiffness of LRB on each pier

		P1	P2	P3	P4	Notation for each pier	
2-piers model	-1	1.00	1.00	—	—	P1, P2：H-Li-Bi-2M P1・P2-1.00	
	-2	0.85	1.30	—	—	P1：H-Li-Bi-2M P1-0.85	P2：H-Li-Bi-2M P2-1.30
4-piers model	-1	1.00	1.00	1.00	1.00	P1, P2, P3, P4：H-Li-Bi-4M Pall-1.00	
	-2	0.85	1.30	1.30	1.30	P1：H-Li-Bi-4M -P1-0.85	P2,P3,P4：H-Li-Bi-4M P2・P3・P4-1.30
	-3	0.85	0.85	0.85	1.30	P1, P2, P3：H-Li-Bi-4M -P1・P2・P3-0.85	P4：H-Li-Bi-4M P4-1.30

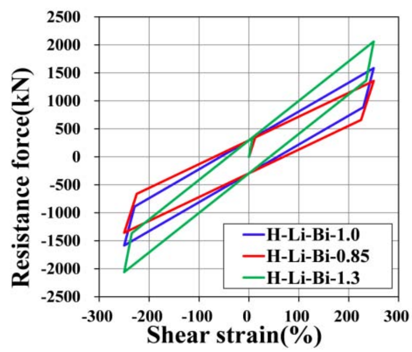
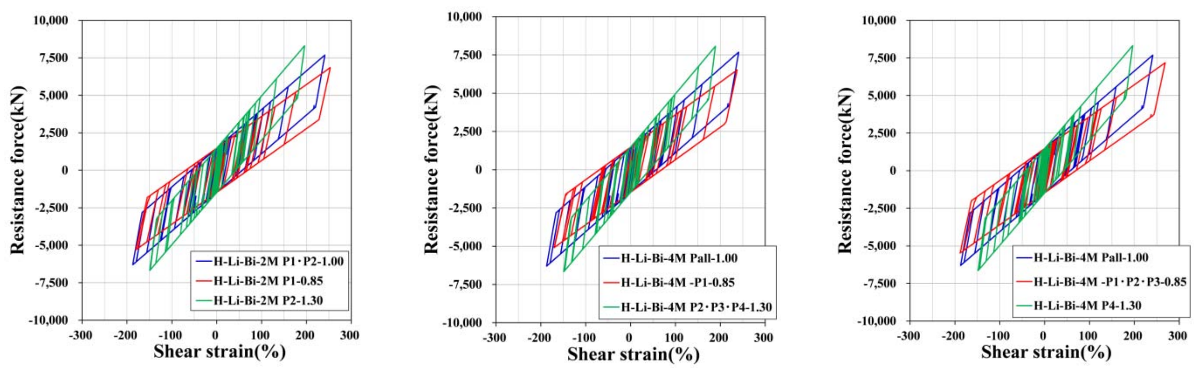


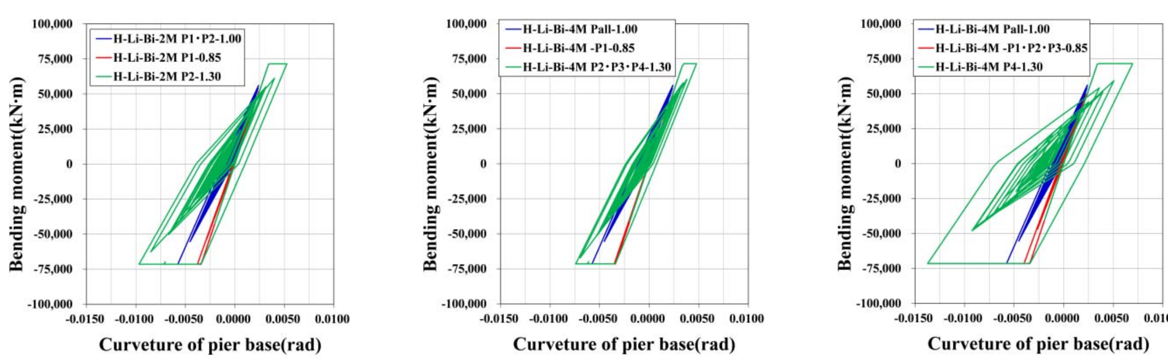
Fig. 24: Hysteresis of LRB on 250%



P1:0.85 – P2:1.30model　　P1:0.85 – P2· P3· P4:1.30model　　P1· P2· P3:0.85 – P4:1.30model

(a)2-piers model　　(b) 4-piers model

Fig. 25: Hysteresis of LRB



P1:0.85 – P2:1.30model　　P1:0.85 – P2· P3· P4:1.30model　　P1· P2· P3:0.85 – P4:1.30model

(a)2-piers model　　(b) 4-piers model

Fig. 26: Hysteresis of pier base

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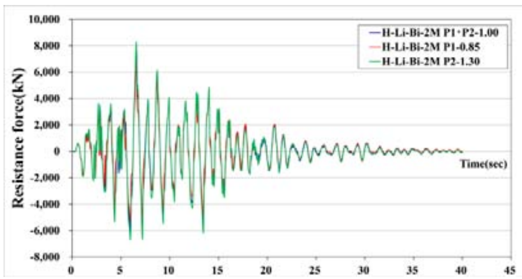
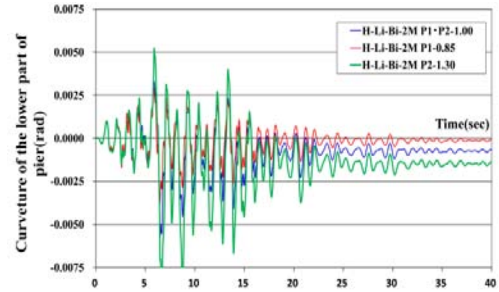
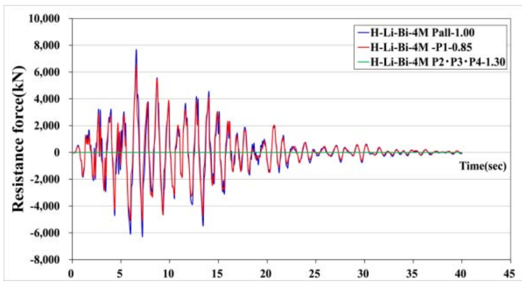


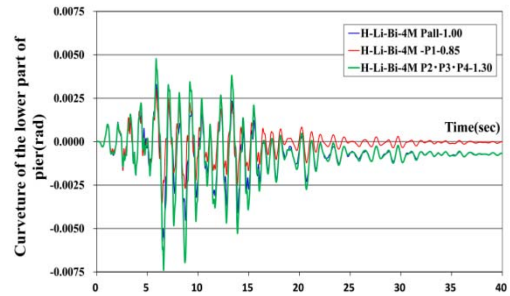
(a) 2-piers modelP1:0.85 – P2:1.30model



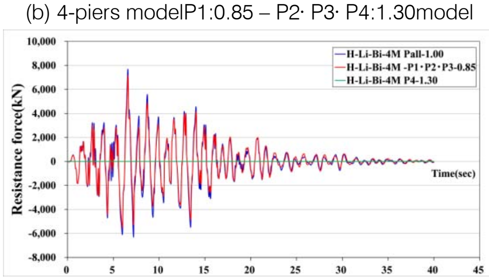
(a) 2-piers modelP1:0.85 – P2:1.30model



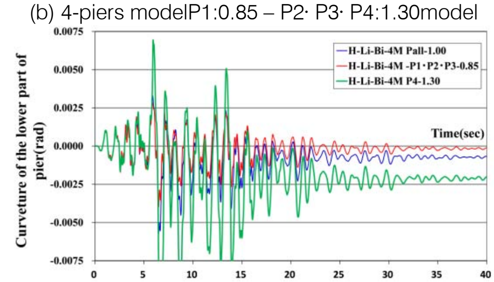
(b) 4-piers modelP1:0.85 – P2· P3· P4:1.30model



(b) 4-piers modelP1:0.85 – P2· P3· P4:1.30model



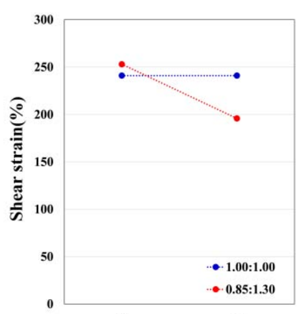
(c) 4-piers modelP1· P2· P3:0.85 –P4:1.30model



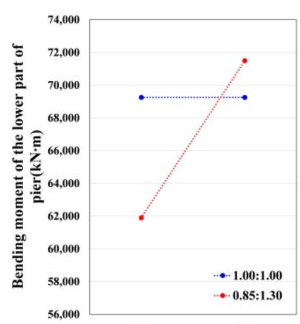
(c) 4-piers modelP1· P2· P3:0.85 –P4:1.30model

Fig. 27: Historical resistance force of LRB

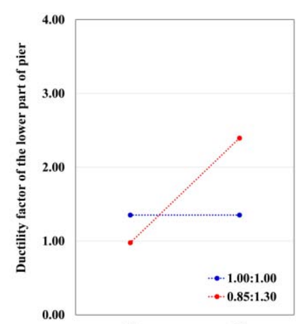
Fig. 28: Historical curvature of pier base



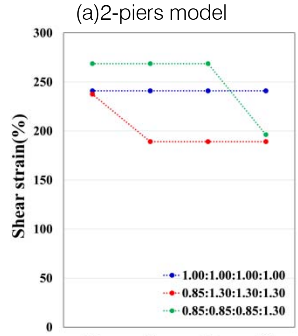
(a)2-piers model



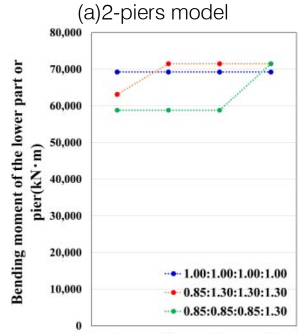
(a)2-piers model



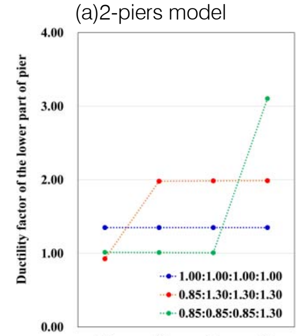
(a)2-piers model



(b)4-piers model



(b)4-piers model



(b)4-piers model

Fig. 29: Shear strain of LRB

Fig. 30: Bending moment of pier

Fig. 31: Ductility factor of pier base

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VIII. Conclusion

Based on the analysis results presented in this paper, the main conclusions are as follows:

1. Considering the hardening of LRB in the current design reduces the maximum shear strain of LRB. In the current design, the maximum shear strain is about 250%, but in the bilinear model and the trilinear model considering hardening, it is reduced to 200% and 230%, respectively. In general, as in this paper, when considering hardening, the maximum shear strain of LRB is set to be larger for the trilinear model than for the bilinear model.
2. Suppose the maximum shear strain of LRB is designed to be 250% according to the current design, considering the decrease in stiffness of 15%, the maximum shear strain of LRB increases to about 300%, so there is a risk of fracture. However, the hardening phenomenon must occur and it becomes difficult to fracture because the shear strain is reduced to about 250% when considered in the bilinear model. In contrast, in the trilinear model, the shear strain is about 270%, which is greater than the allowable shear strain 250%. In conclusion, when designing in consideration of hardening, it is necessary to review the modeling method of hardening.
3. It is necessary to understand that in a seismic isolation bridge, the predominant period depends not only on the difference in seismic waves but also on LRB hysteresis setting and nonlinearity.
4. When the allowable ductility factor of the pier is set to be small, such as a seismic isolation bridge, it is expected that the effect of the over strength of the pier on the maximum shear strain of LRB is small. On the contrary, in the design of plasticizing piers largely, it is necessary to pay attention to the increase in the maximum shear strain of the bearings due to the over strength of the piers. Based on the results presented in this paper, it was confirmed that LRB performance in the current design of LRB is difficult to become larger than the expected response in the design due to the hardening occurring in the high deformation region even if the stiffness decreases due to various dependencies or durability. In addition, in the seismic isolation design with limited plasticization of the pier, the effect of the over strength of the pier was found to be small. In conclusion, it means that when the seismic isolation design according to the current design is applied in the actual design, the response of LRB due to the performance change of the bearing (LRB) or the over strength of the pier does not significantly exceed the allowable shear deformation.
5. If the stiffness of LRB between piers is different from the design value, the response of LRB with small stiffness increases due to the difference, or the piers with LRB with high stiffness are large plasticized. This means that it is different from the expected value of the design. There are various factors for fluctuations in LRB between piers. Therefore, it is important to manufacture in the same manufacturing process as LRB used in the same pier in order not to cause a relative difference in LRB between piers.

IX. Afterword

In this paper, LRB seismic safety was evaluated in cases where the stiffness of LRB is smaller than the design stiffness and the yield load of the pier is increased by selecting a single column pier model in a bridge using LRB. In this regard, if the stiffness of LRB is greater than the design expected, there is a possibility that a large inertia force acts on the pier and the safety of the pier is lost when the earthquake occurs. However, in general, the design of piers has a greater allowance during an earthquake than LRB, and the yield load of piers due to over strength is greater than the value determined in the design. In addition, since the earthquake safety factor of the seismic isolation designed pier is twice that of the distributed bearing (RB), it is thought that there is a large allowance for the safety during an earthquake, but it is important to note that an earthquake behavior of the seismic isolation bridge is not necessarily guaranteed. For this reason, it is necessary to evaluate the safety of the pier by increasing the response of the pier of the seismic isolation bridge. In addition, a case study was conducted on the effect of the stiffness change of LRB between piers on the dispersion of the inertia force of the continuous girder. Depending on the pier, there are various factors that affect the stiffness of LRB. Therefore, it is important to manufacture LRB in the same manufacturing process so that stiffness does not change. In this paper, the statically indeterminate force due to temperature change and the characteristics of the foundation were not verified as factors that increase the response of the seismic isolation bearing. Among them, temperature change is a clearly occurring phenomenon, and if the length of the extension girder is long, like a multi-span continuous girder bridge, the effect on the earthquake response at low and high temperatures is clearly evident. Most of the statically indeterminate force is generated by plasticizing the pier, which increases the ductility factor and residual displacement of the pier, and also increases the response variation and residual displacement of the bearing. This means that bridges that are likely to have increased the statically indeterminate force need to check their behavior during an earthquake in the state of deformation when the temperature changes. In addition, since the temperature change affects the hysteresis characteristics of the bearing, it is preferable to use the

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hysteresis shape in consideration of these factors. However, in general, it is not necessary to consider a bridge that is not long because the temperature change has a small effect on the response during an earthquake. On the other hand, the variation in the dispersion of the inertia force of the continuous girder is likely to be influenced by the performance variation of the seismic isolation bearing of the pier. Therefore, in order to reduce the relative performance fluctuation between the seismic isolation bearings, it is necessary to make the manufacturing lot of the seismic isolation bearing used in the bridge almost identical. As a result, it can be expected that the effect on the horizontal force distribution of the continuous girder is reduced and the behavior is difficult to damage during an earthquake determined in the structural design [8]. The influence of the characteristics of the foundation of the ground is expected to vary widely. Therefore, since it is difficult to set design conditions, it is necessary to prevent ground fluctuations from affecting the response during an earthquake through secondary plasticization of piers like a seismic isolation bridge.

Appendix

Formula for R_k in East, Central and West Japan Expressway co., Ltd. Construction Management Guidelines [11]

$$R_{k+} = +\sqrt{\left(R_{k(Initial)}\right)^2 + \left(R_{k(Period)}\right)^2 + \left(R_{k(Temperature)}\right)^2 + \left(R_{k(pressure)}\right)^2} + \left(R_{k(Compression\ fatigue)}\right) + \left(R_{k(Shear\ fatigue)}\right) \leq 0.30$$

$$R_{k-} = -\sqrt{\left(R_{k(Initial)}\right)^2 + \left(R_{k(Period)}\right)^2 + \left(R_{k(Temperature)}\right)^2 + \left(R_{k(pressure)}\right)^2} + \left(R_{k(Compression\ fatigue)}\right) + \left(R_{k(Shear\ fatigue)}\right) \geq -0.1$$

Where each R_k is the ratio representing the change in various factors.

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3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
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7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

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The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

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Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

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Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

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6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

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- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

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This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

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References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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