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DESIGN OF RIGID L-SHAPED RETAINING WALLS

NANOTECHNOLOGY IN CIVIL ENGINEERING AND CONSTRUCTION

SEISMIC ANALYSIS OF INTERLOCKING MORTAR-LESS HOLLOW BLOCK

WHAT CAUSED KOLKATA FLYOVER COLLAPSE?

COMPARATIVE STUDY BETWEEN DIFFERENT TYPES OF FORMWORK

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Design of Rigid L- Shaped Retaining Walls

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Abstract**—**Cantilever L-shaped walls are known to be relatively economical as retaining solution. The design starts by proportioning the wall dimensions for which the stability is checked for. A ratio between the lengths of the base and the stem, falling between 0.5 to 0.7 ensure in most case the stability requirements, however, the displacement pattern of the wall in terms of rotations and translations, and the lateral pressure profile, do not have the same figure for all wall's proportioning, as it is usually assumed. In the present work the results of a numerical analysis are presented, different wall geometries were considered. The results show that the proportioning governs the equilibrium between the instantaneous rotation and the translation of the wall-toe, also, the lateral pressure estimation based on the average value between the at-rest and the active pressure, recommended by most design standards, is found to be not applicable for all walls.

Keywords**—**Cantilever wall, proportioning, numerical analysis.

I. Introduction

RIGID cantilever L - shaped retaining walls are considered as complex type of geotechnical structures, particularized by the fact that they are not only supported by the soil, as is the case with foundations, but also loaded by the soil. Actual design methodology does not take into account the real geometry of the wall and the acting lateral pressure magnitude and distribution. Most of the well known codes of practices assume a simple hydrostatique stress distribution, acting on 'the virtual' wall, based on the Coulomb's and Rankine's theories. The geometry (shape and dimensions) is a key issue in investigating retaining structures. Previous researches suggest different values of the ratio of the wall height to base. An average value of 0.5 was suggested by Powerie and Chandler [1], and suggested later as optimum by Daly and Powerie [2]. It is obvious that there is no clear guidance on the value of this ratio. It is suggested in the followings, to investigate the effect of the 'dimensions' parameters on the overall behavior of the particular L-shaped retaining wall.

In the present investigation the effect of the geometry (designated by *WH* and the ratio *B/H*) on the behavior of the L-shaped rigid retaining wall is investigated with a numerical model, developed and validated with respect to the geometry, dimensions, boundary conditions and the loading conditions of a reference system presented in Fig. 1. This system was investigated by previous researchers in a centrifuge experiment conducted on a reduced scale prototype [3].

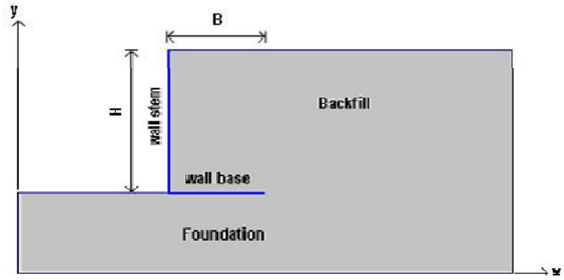

Fig. 1 Reference system

II. Geometry of the Wall

In order to investigate the effect of the height of the wall and the horizontal length of the base, 3 L-shaped walls were considered: a 2m height wall (designated by *WH2*), a 5m height wall (*WH5*) and a 9m height wall (*WH9*). The walls considered remain very stiff. To account for the effect of the base on the lateral pressure distribution, the ratio *B/H* was introduced as variable parameter, where *H* is the height of the stem of the wall and *B* is the corresponding horizontal base length: 4 ratios were investigated in the present study, 0.3, 0.5, 0.8 and 1.0 to account for the lower bound and the upper bound behaviors, and includes the actual design practice, recommended values falling between 0.5 and 0.8 [4].

The present approach allowed to investigate the direct effect of the parameters *H* and *B/H* on the displacement pattern and the lateral pressure acting on the L–shaped retaining wall. The values of *H* considered were assumed to represent the behavior of distinctive wall dimensions including the height of the wall considered in the development of the numerical model (H=9m). The combination of the (*H*) and (*B/H*) parameters yields to the numerical analysis of 12 different L-shaped retaining walls. The designation adopted for the different parametric walls is presented in the Table I, were for example the wall designated by *WH2BH03* stands for a 2 meter height L-shaped wall with a ratio of its height over the length of its base *(H/B)* equal to 0.3 (*BH03*).

TABLE I
Designation of the Parametric Walls

	B/H			
H **(m)**	**0.3**	**0.5**	**0.8**	**1.0**
2	*WH2BH03*	*WH2BH05*	*WH2BH08*	*WH2BH1*
5	*WH5BH03*	*WH5BH05*	*WH5BH08*	*WH5BH1*
9	*WH9BH03*	*WH9BH05*	*WH9BH08*	*WH9BH1*

III. Soil and Walls Modeling

The numerical analysis was carried out in plane strain, the entire model extends 28m horizontally and 14m vertically, to account for the centrifuge dimensions box converted to the prototype scale. The retaining walls are defined through an L-Shaped beam (with a rigid slab footing) representing the prototype dimensions of the centrifuge model. Conditions of plane strain were assumed throughout. Fig. 2 shows a typical finite element model with the displacement boundary conditions. The retaining wall was modeled by beam elements with a Young's modulus (reinforced concrete) assumed with $E_b= 3 \cdot 10^4$ MN/m2. The soil has been modeled using the hardening soil model, considered in drained conditions [5]. The soil modeling parameters are presented in Table II.

TABLE II
MODELING PARAMETERS OF THE SOIL

$E_{oed\,ref}$ [MN/m^2]	$E_{50\,ref}$ [MN/m^2]	$E_{ur\,ref}$ [MN/m^2]	m	Φ [°]	c	Ψ [°]
25	25	100	0.65	35	0	2.5

The numerical modeling concept used for the validation of the numerical model developed together with its possible limitations has been fully investigated by Rouili et al. [6] and [7].

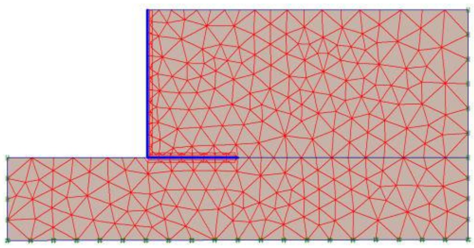

Fig. 2 Typical finite element model

IV. Numerical Calculations and Results

The calculation was carried for each wall separately; the calculation process starts from a stage of initial condition with different wall dimensions. The calculation progresses until the prescribed ultimate state is fully reached. A typical post processing deformed meshes corresponding to the walls *WH5BH05 is* presented in Fig. 3.

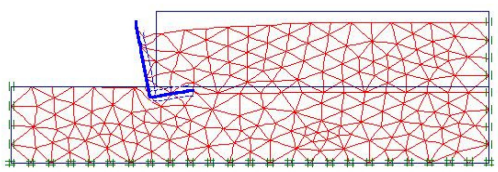

Fig. 3 Typical deformed mesh (wall *WH05BH05*)

V. Displacement of the Wall

For all the walls the bending deflection are negligible and the measured horizontal and vertical displacements reported concerns the rigid body movements. As illustrated in Fig. 4, δ_{ht} represents is the horizontal movement of the top of the wall (displacement of the point A_n); δ_{hb} is the horizontal movement of the bottom of the wall (horizontal displacements of the points B_n and C_n); δ_v is the vertical movement of the wall (nodal vertical displacement of the points A_n and B_n).

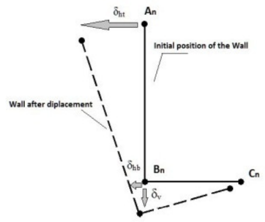

Fig. 4 Displacement Pattern of the Wall

Figs. 5-8 show the computed displacement of the nodal point B_n plotted against the multiplier, corresponding respectively to the walls having the ratio *B/H* =0.5 to *B/H =1*. As it is clear from these figures, the displacements path corresponding to *B/H*=0.3 plotted on Fig. 5 and the displacement path for *B/H*=0.5 plotted on Fig. 6 follows a curved lines which indicates the rotation effect, however, the displacement paths corresponding to *B/H*=0.8 plotted on Fig. 7 and the displacement path for *B/H*=1 plotted in Fig. 8 are closely linear which indicates the translation effect.

As far as the geometry if the L-shaped wall is concerned, it could be concluded from the present analysis that, the length of the wall base through the ratio *B/H* governs the equilibrium between the instantaneous rotation and the translation of the wall-toe. It was shown that for values of *B/H* less than 0.5 the rotational movement is dominant. However, for values of *B/H* over 0.8 the translation of the toe is more pronounced. The design practice of *B/H* laying between 0.5 and 0.8, remains reasonable as far as the equilibrium between the rotation and translation of the wall is concerned. These observations are summarized in the chart of Fig. 9.

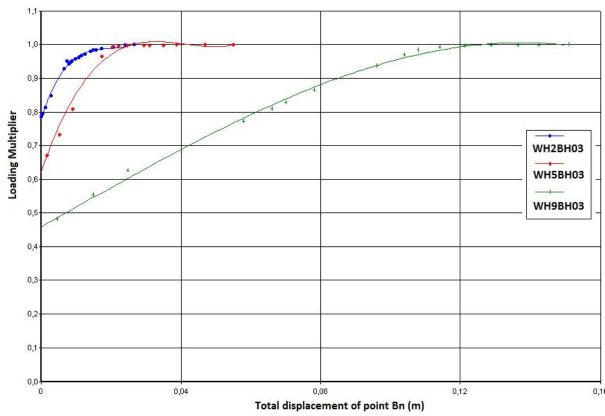

Fig. 5 Total displacements of the Point Bn (*B/H=0.3*)

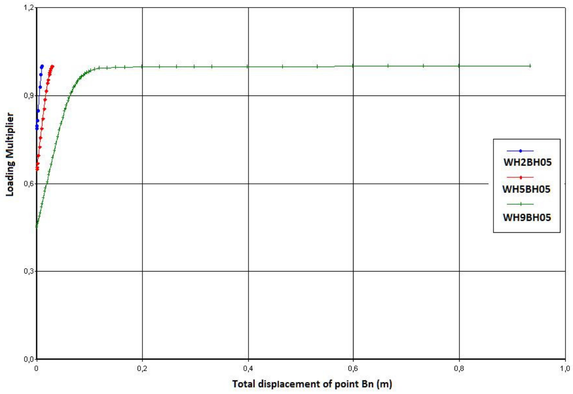

Fig. 6 Total displacements of the Point *Bn* (*B/H=0.5*)

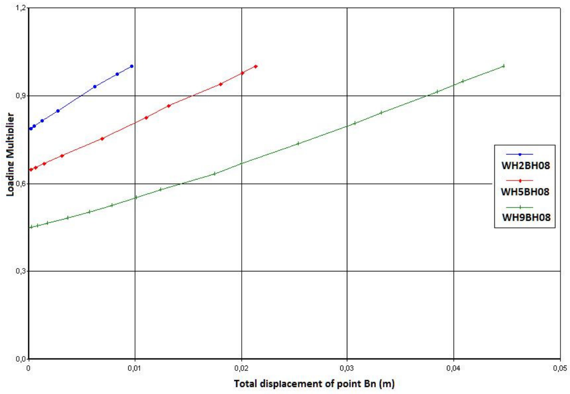

Fig. 7 Total displacements of the Point *Bn* (*B/H=0.8*)

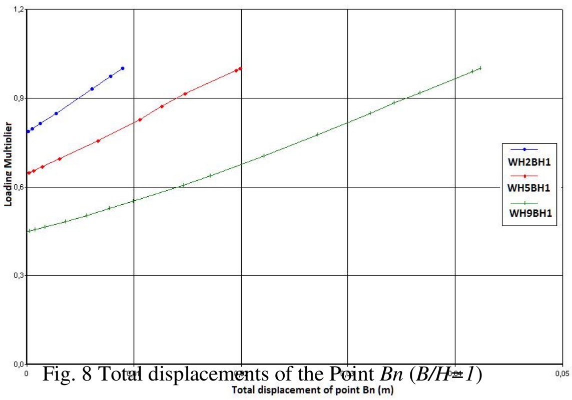

Fig. 8 Total displacements of the Point *Bn* (*B/H=1*)

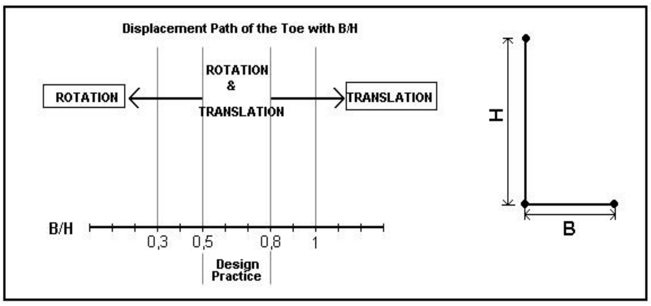

Fig. 9 Displacement chart of the L-shaped wall

VI. Lateral Pressure Acting on the Walls

Fig. 10 shows the lateral pressures profiles as a results of varying the wall-stem height (*WH*) and the ratio *B/H*. Following the increase of the ratio *B/H* for each wall, it could be noticed that the lateral pressure seem to increase accordingly, this effect could be attributed to the relative pressure applied by the weight of the backfill soil resting on the wall base. On this figures it is also plotted the repartition of the lateral pressure computed using the Rankine approach. It could be argued that as far as the distribution of the lateral pressure acting on the wall-stem is concerned, the design approach does not apply for all the L-shaped geometries investigated, especially, when the lateral pressure is estimated out of the average, between the active and the at-rest conditions. On these figures it is also evident, that in the lower third of the walls height, there is an abrupt change with deceasing values of the lateral pressure (slope), this is common to all the walls considered but at different depth noted. It could be argued that the position of the lateral pressure change depends uniquely on the height of the wall and seems not influenced by the base length.

In Fig. 11 shows the lateral pressure profiles as a result of varying the base length through the ratio *B/H* and the wall height (*WH*). From this figures it could be seen that the slopes and magnitudes of the lateral pressures acting on the different walls are nearly comparable regardless the wall-stem height.

On Fig.12 the computed lateral pressure coefficients *Kc,* corresponding to the walls *WH2, WH5* and *WH9*, for value of the ratio *B/H* falling between 0.5 and 0.8 (recommended design limits), are plotted against the variation of the coefficient of the lateral pressure. For appreciation of the results 2 bounds limits of the lateral pressure coefficient were fixed (according to the design practice), the upper limit is the presentation of the at-rest coefficient K_0 , and the lower limit is the coefficient K_a corresponding to the active pressure (for δ=0), the average value i.e. 0.5 ($K_a + K_0$) is also plotted. From this figure it could be argued that, for all walls considered there is a unique figure, the value of *Kc* falls all above the active pressure of the soil, and seems to increase with the value of the ratio *B/H*, but remains below the average limits usually considered in design practice which implies an overestimation of the lateral pressure.

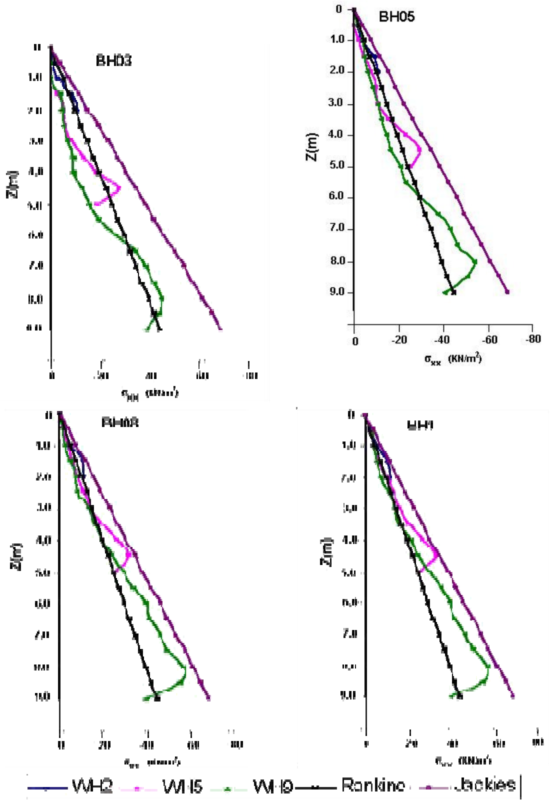

Fig. 10 Lateral pressure profile all-walls

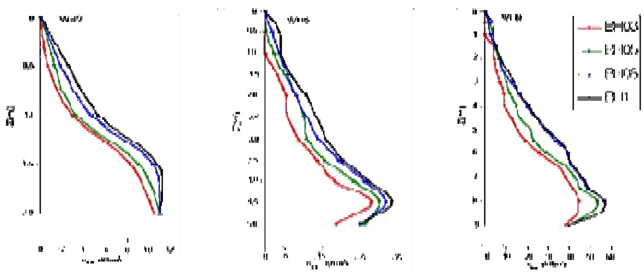

Fig. 11 Lateral pressure variation *WH*

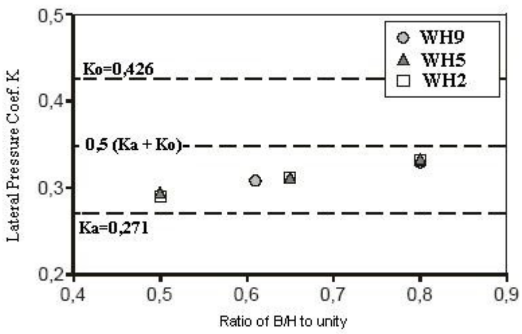

Fig. 12 Earth pressure coefficient dependent on *B/H*

VII. Conclusion

In the present work the results of a numerical analysis are presented, different wall geometries were considered. The results show that the proportioning governs the equilibrium between the instantaneous rotation and the translation of the wall-toe; also, the length of the wall base through the ratio *B/H* governs the equilibrium between the instantaneous rotation and the translation of the wall-toe. It was shown that for values of *B/H* less than 0.5 the rotational movement is dominant. However, for values of *B/H* over 0.8 the translation of the toe is more pronounced. The design practice of *B/H* lay between 0.5 and 0.8, remains reasonable as far as the equilibrium between the rotation and translation of the wall is concerned.

The lateral pressure estimation based on the average value between the at-rest and the active pressure, recommended by most design standards, is found to be not applicable for all walls. For all walls considered in the present exercise, there is a unique figure, the values of the computed lateral pressure coefficients (*Kc*) falls all above the active pressure of the soil, and seems to increase with the value of the ratio *B/H*, but remains below the average limits usually considered in design practice which implies an overestimation of the lateral pressure.

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Seismic analysis of interlocking mortar-less hollow block

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A B S T R A C T

Various types of interlocking mortarless (dry-stacked) block masonry systems have been developed worldwide. However, the characteristics of dry joints under compressive load, and their effect on the overall behavior of the interlocking mortarless system, are still not well understood. This paper presents an investigation into the dry-joint contact behavior of masonry and the behavior of interlocking mortarless hollow blocks wall construction subjected to seismic excitation. In the system developed, the blocks are stacked on one another and three-dimensional interlocking pro-trusions are provided in the blocks to integrate the blocks into walls. The response of the mortarless hollow block wall with respect to acceleration displacement and stress have been discussed.

Keywords:

Masonry systems Seismic analysis Mortar less block
Interlocking block Finite element method.

1. Introduction

Interlocking mortarless load bearing hollow block system is different from conventional mortared masonry systems in which the mortar layers are eliminated and instead the block units are interconnected through interlocking protrusions and grooves. Numerous analytical models have been developed to simulate the behavior of different types of structural masonry systems using Finite element method. Two main approaches have been employed in the masonry modeling depending on the type of the problem and the level of accuracy. The macro-modelling approach intentionally makes no distinction between units and joints but smears the effect of joints presence through the formulation of a fictitious homogeneous and continuous material equivalent to the actual one which is discrete and composite (Lotfi and Shing, 1991; Cerioni and Doinda, 1994; Zhuge et al., 1998). The alternative micro- modelling approach analyzes the masonry material as a discontinuous assembly of blocks, connected to each other by joints at their actual position, the latter being simulated by appropriate constitutive models of interface (Suwalski and Drysdale, 1986; Ali and Page, 1988; Riddington and Noam, 1994). An extensive critical review for the analytical models of different masonry systems can be found in the performed study done by Alwathaf et al. (2003).

The complex interaction between block units, dry joint and grouting material has to be well understood under different stages of loading; i.e. elastic, inelastic and failure. For interlocking mortarless masonry systems, very limited FE analyses have been reported in the literature (e.g., Oh, 1994; Alpa et al., 1998).

The existing FE analyses are simplified and hence show inaccurate prediction for the structural response of the masonry systems compared to actual behavior of the systems found experimentally. Furthermore, the existing models ignore the interaction between masonry block units, mortarless joint and grout as well as are incapable of simulating the failure mechanism of the masonry system.

In this study, a finite element model is proposed and a program code is developed to predict the behavior of the system under compression load. The developed con-tact relations for dry joint within specified bounds can be used for any mortarless masonry system efficiently with less computational effort. The bond between block and grout is considered to simulate the deboning and slipping of the block–grout interface. Furthermore, the stress–strain behavior of masonry blocks and grout ma-terials under compression for uniaxial and biaxial stress state was modelled.

2. Modelling of Mortarless Joint

In present study, the hollow prisms modelled using eight- noded isoparametric elements to simulate the masonry constituents, are shown in Fig. 1(a). Six-noded isoparametric interface element of zero thickness located between material elements to model the interface characteristics of the dry joint and bond between blocks are represented in Figs. 1(b-c), respectively. Fig. 2 shows the finite element geometric model of considered wall that was constructed by hollow blocks. Dimension of this model are 3 m width and 3 m height assumed. Therefore by considering the dimensions of each prism (30 cm with and 20 cm height), there are 10 prisms in horizontal and 15 prisms of hollow block in vertical direction.

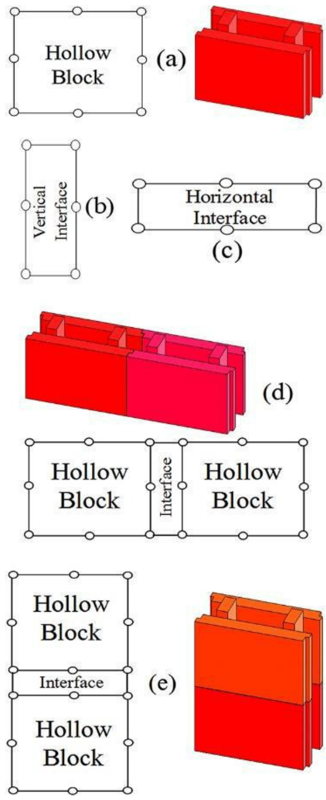


Fig. 1. (a) 8 node elements that was used for modeling of hollow block prism. (b) 6 node elements that was used for modeling of zero thickness vertical interface. (c) 6 node elements that was used for modeling of zero thickness horizontal interface. (d) Connection of two horizontal hollow block elements with vertical interface. (e) Connection of two vertical hollow block elements with horizontal interface.

In this finite element mesh as shown in Fig. 1(d) vertical dry joint between 2 horizontal block has been mod-elled by 6 node zero thickness vertical interface element and horizontal dry joint between 2 vertical block has been modelled by 6 node zero thickness horizontal inter-face element (Fig. 1(e)).

The considered wall is assembled by 150 blocks elements and 140 interface elements and model prepared by 865 elements and 2400 nodes. Therefore the final finite element mesh of wall is shown in Fig. 3.

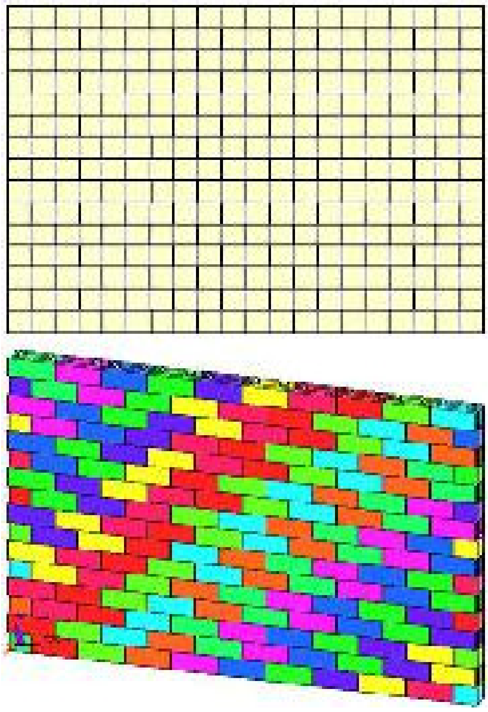


Fig. 2. Geometry of considered wall with 3 m width and 3 m height.

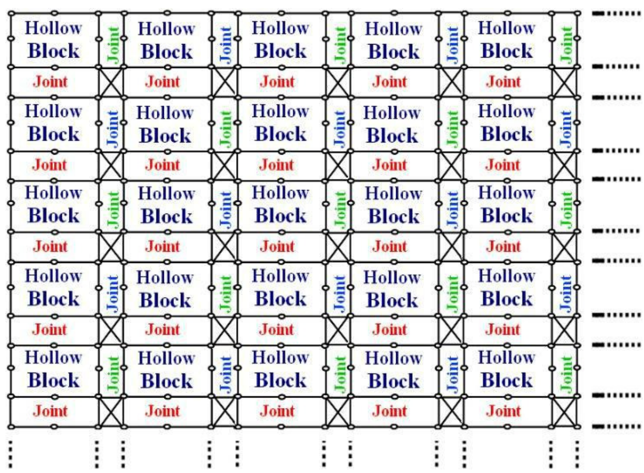


Fig. 3. Finite element model of hollow block wall.

3. Finite Element Analyses

A finite element program code has been developed to implement the proposed mortar-less masonry model under seismic loading. Time history dynamic analysis of wall by imposing of suitable earthquake record for Ma-laysia and Indonesia are performed and shown in Fig. 4.

The time step of Malaysia earthquake record is 0.02 sec and duration of that is 20 sec and time step and duration of Indonesia record is 0.01 sec and 10 sec, respectively. Deformation of wall in imposing Malaysia and Indonesia earthquake excitation is shown in Fig. 5.

As seen in Fig. 5, top nodes of wall have high displacement in comparison with bottom nodes of wall and maximum displacement of wall occurs in the last top row of wall.

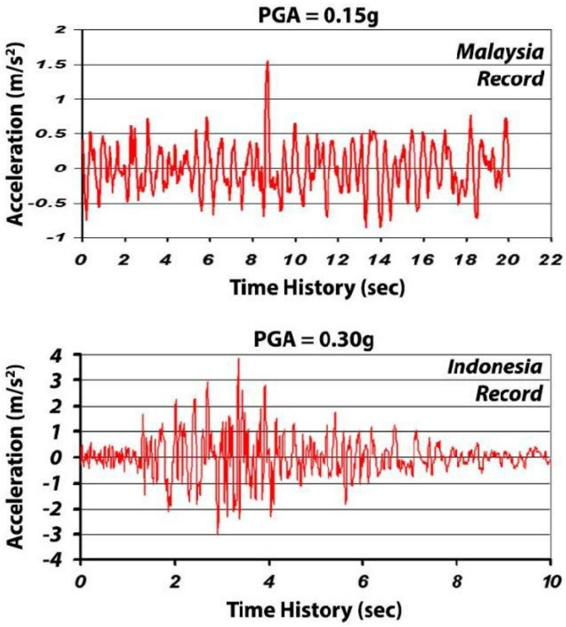


Fig. 4. Earthquake acceleration record for Malaysia and Indonesia.

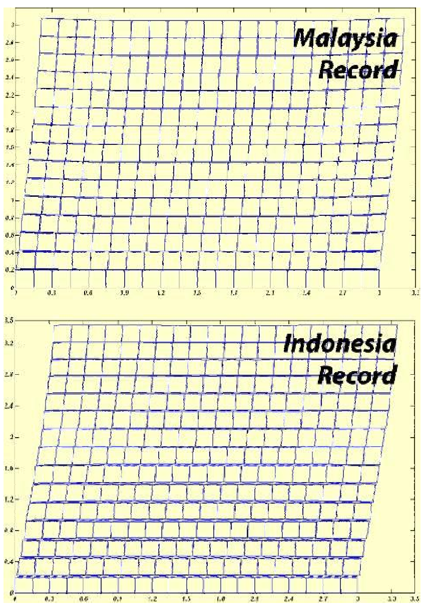


Fig. 5. Deformation of hollow block wall in Malaysia and Indonesia earthquake excitation (10 times exagger-ation in *x* and *y* directions).

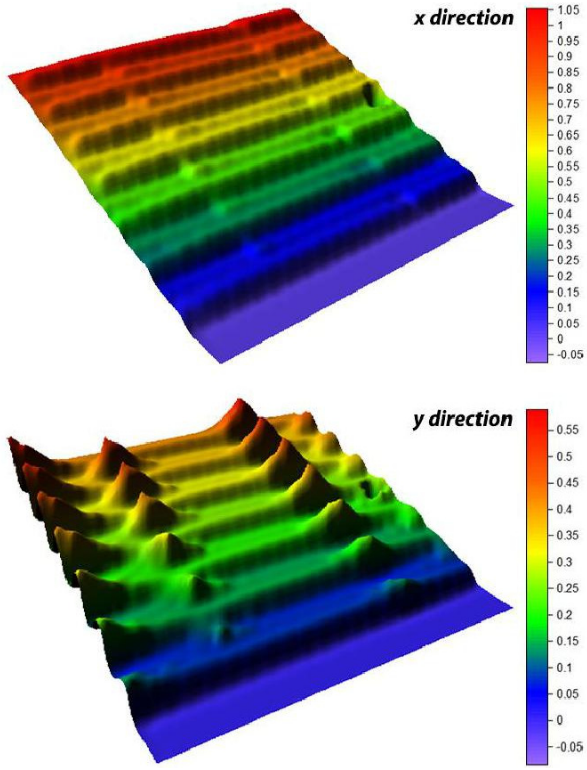


Fig. 6. Malaysia peak displacements in *x* and *y* direc-tions (cm).

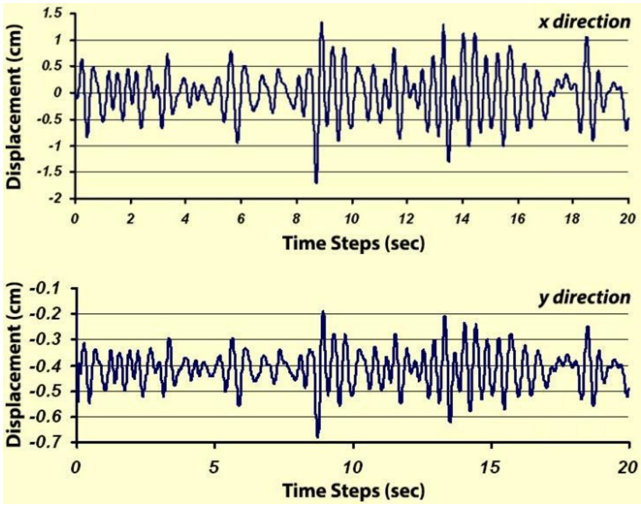


Fig. 7. Time-displacement history of top node of wall in *x* and *y* directions (cm).

4. Results and Discussion

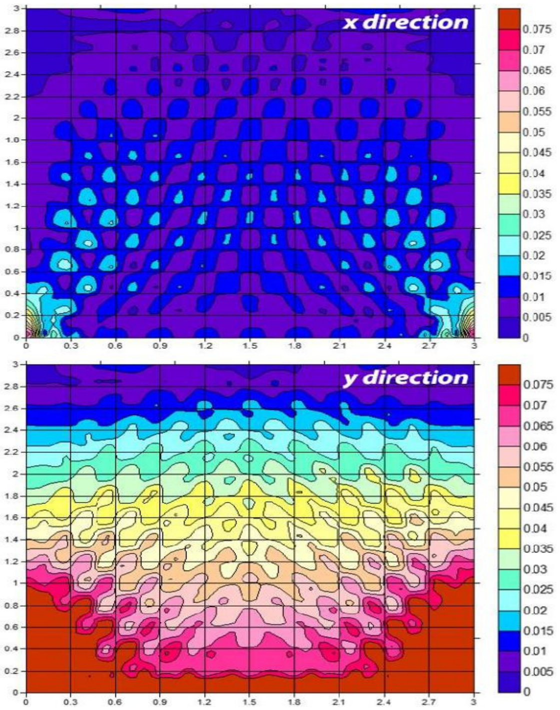
4.1. Malaysia record excitation

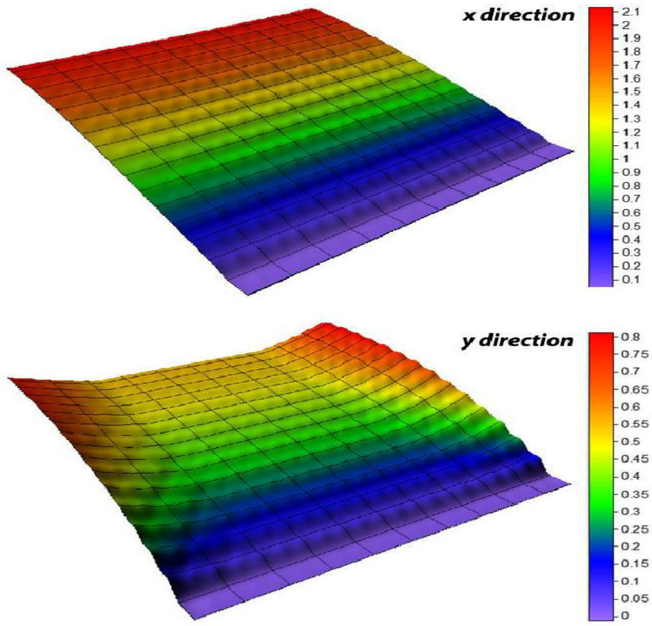
Peak value of nodes' displacement in *x* and *y* directions during the earthquake excitation is determined by dynamic analyzes and values of that are plotted in Fig. 6.

The maximum displacement in *x* direction is 1.73 cm and in *y* direction is 0.71 cm. These values were less than allowable displacement for a masonry wall which were acceptable. The time history response and movement of wall during Malaysia earthquake load excitation, at top node of wall in *x* and *y* directions are shown in Fig. 7.

Peak value of each element stress *x* and *y* directions during the time steps of earthquake excitation are shown in Fig. 8. The maximum principle stress in *x* and *y* directions at bottom of wall is equal to 0.05222 and 0.1701 MPa.

Stress at bottom of wall is shown in Fig. 9. The stress values are very small because just single story building with very lightweight roof has been considered. Also just horizontal component of earthquake load imposed to wall and vertical component is neglected. So, maximum stresses in wall members are very smaller than the strength of blocks. Therefore the hollow block can be re-sist Malaysia earthquake excitation with allowable de-formation and stress





5. Conclusions

Based on the foregoing analysis and discussion of the test results from this investigation, several conclusions can be drawn as follows.

1. Finite element model of mortar-less block masonry system has been developed. The model is at micro-level which includes the modelling of masonry materials, mortar-less dry joint and block-grout interface behaviour.

2. The interlocking keys provided for this system were able to integrate the blocks into a sturdy wall and can re-place the mortar layers that are used for conventional masonry construction in low seismic area.

3. Considered wall system can be resist in Malaysia earthquake record excitation (PGA=0.15g, low seismic hazard level) but in Indonesia earthquake record excitation (PGA=0.39g, high seismic hazard level), displacement of wall is exceed allowable values. Therefore this type of wall that constructed by explained hollow blocks just resist low seismic excitation.

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NANOTECHNOLOGY IN CIVIL ENGINEERING AND CONSTRUCTION

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ABSTRACT:
Nanotechnology is the science of engineering that deals with particle which are less than 100 nm in size. It is the study of manipulating matter on molecular and atomic scale. In recent years, nanotechnology showed its potential in the field of biomedical, electronics, robotics. In civil engineering and construction, the nanotechnology is applied in (i) concrete for reducing segregation in self compacted concrete, (ii) the use of copper nano-particles in low carbon HPS is remarkable, (iii) the use of nano sensors in construction phase to know the early age properties of concrete is very useful, and (iv) its use in water purification system by replacing the use of granulated particles of carbon in filtration with purifiers like Nano Ceram-Pac (NCP). The present paper reviews the state of the art on the use of nanotechnology in the field of civil engineering and construction and also discusses its future prospect. Also, special emphasis is placed on the future application of nanotechnology in the field of geotechnical engineering.

INTRODUCTION

Nanotechnology is the use of very small particles of material either by themselves or by their manipulation to create new large scale materials. Nanotechnology is not a new science and it is not a new technology. It is rather an extension of the sciences and technologies.

The emergence of nanotechnology in the 1980s was caused by the convergence of experimental advances such as the invention of the scanning tunneling microscope in 1981 and the discovery of fullerenes in 1985, with the elucidation and popularization of a conceptual framework for the goals of nanotechnology beginning with the 1986 publication of the book *Engines of Creation*. In brief, the technology enables us to develop materials with improved properties or it can be used to produce a totally new material.

Nanotechnology deals with particle at nano-scale, i.e., 10^{-9} m. At "nano scale" the world is different from "macro scale", e.g., the gravity becomes unimportant, electrostatic forces take over and quantum effects emerge. As particles become nano-sized, the proportion of atoms on the surface increases relative to those inside leads to "nano-effects", however, that ultimately determine all the properties that we are familiar with at our "macro-scale" and this is where the power of nanotechnology comes in.

Following are the major application of nanotechnology in the field of (*i*) nanomedicine, (*ii*) Environment, (*iii*) Energy, (*iv*) nanobateries, (v) Information and communication, (vi) Heavy industry etc. In recent years nanotechnology is also gaining popularity in the field of Civil Engineering and construction.

OBJECTIVES

In view of that the paper reviews the state of the art practice of nanotechnology in different fields of civil engineering and construction with the following objectives: The paper reviews the state of the art "application of nanotechnology in civil engineering and construction". Emphasis is also placed in potential use of technology in the field of geotechnical engineering.

NANOTECHNOLOGY IN CONSTRUCTION

The use of nanotechnology in construction involves the development of new concept and understanding of the hydration of cement particles and the use of nano-size ingredients such as alumina and silica and other nanoparticles. With the help of nanotechnology, concrete is stronger, more durable and more easily placed, steel is made tougher, glass is self cleaning and paints are made more insulating and water repelling.

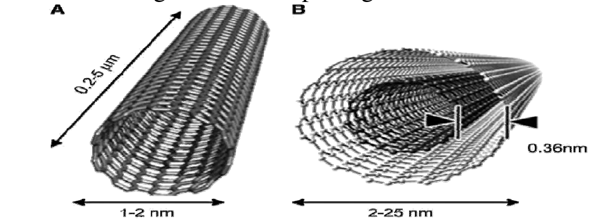

Fig. 1 Conceptual diagram of single-walled carbon nanotube (*SWCNT*) (A) and multiwalled carbon nanotube (*MWCNT*) (B) delivery systems showing typical dimensions of length, width, and separation distance between graphene layers in *MWCNTs*

Two nano-sized particles that stand out in their application to construction materials are titanium dioxide (TiO_2) and carbon nanotubes (*CNT's*). The former is being used for its ability to break down dirt or pollution and then allow it to be washed off by rain water on everything from concrete to glass and the latter is being used to strengthen and monitor concrete.
Carbon nanotubes (*CNTs*) are cylindrical in shape with diameter in nanometers and length can be in several millimeters as shown in Fig. 1. When compared to steel, the

Young's modulus of *CNTs* is 5 times, strength is 8 times while the densite is $1/6^{th}$ times. Along the tube axis the thermal conduction is also very high.

Titanium dioxide is widely used as white pigments. It can also oxidize oxygen or organic materials, therefore, it is added to paints, cements, windows, tiles, or other products for sterilizing, deodorizing and anti-fouling properties and when incorporated into outdoor building materials can substantially reduce concentrations of airborne pollutants. Additionally, as TiO_2 is exposed to *UV* light, it becomes increasingly hydrophilic (attractive to water), thus it can be used for anti-fogging coatings or selfcleaning windows.

Nanotechnology and Concrete

As reported in [1], much analysis of concrete is being done at the nano-level in order to understand its structure using the various techniques developed for study at that scale such as Atomic Force Microscopy (*AFM*), Scanning Electron Microscopy (*SEM*) and Focused Ion Beam (*FIB*). The understanding of the structure and behavior of concrete at the fundamental level is an important and very appropriate use of nanotechnology.

One of the advancements made by the study of concrete at the nanoscale is that particle packing in concrete can be improved by using nano-silica which leads to a densification of the micro and nanostructure resulting in improved mechanical properties. Nano-silica addition to cement based materials can also control the degradation of the fundamental C-S-H (calcium-silicatehydrate) reaction of concrete caused by calcium leaching in water as well as block water penetration and therefore lead to improvements in durability. Related to improved particle packing, high energy milling of ordinary portland cement (*OPC*) clinker and standard sand, produces a greater particle size diminution with respect to conventional *OPC* and, as a result, the compressive strength of the refined material is also 3 to 6 times higher (at different ages).

Another type of nanoparticle added to concrete to improve its properties is titanium dioxide (TiO_2). TiO_2 is a white pigment and can be used as an excellent reflective coating. Since TiO_2 breaks down organic pollutants, volatile organic compounds, and bacterial membranes through powerful catalytic reactions, it can therefore reduce airborne pollutants when applied to outdoor surfaces. Additionally, it is hydrophilic and therefore gives self cleaning properties to the applied surfaces. In this process rain water is attracted to the surface and forms sheets which collect the pollutants and dirt particles previously broken down and washes them off. The resulting concrete has a white colour that retains its whiteness very effectively.

Research is being carried out to investigate the benefits of adding *CNT*'s to concrete. The addition of small amounts (1% wt) of *CNT*'s can improve the mechanical properties of samples consisting of the main portland cement phase and water. Oxidized multi-walled nanotubes (*MWNT*'s) show the best improvements both in compressive strength (+25 N/mm^2) and flexural strength (+8 N/mm^2) compared to the reference samples without the reinforcement. However, two problems with the addition of carbon nanotubes to any material are the clumping together of the tubes and the lack of cohesion between them and the matrix bulk material. Additional work is needed in order to establish the optimum values of carbon nanotubes and dispersing agents in the mix design parameters. In addition, the cost of adding *CNT*'s to concrete may be prohibitive at the moment.

Balaguru [2] stated that Self Compacting Concrete (*SCC*) is one that does not need vibration in order to level off and achieve consolidation. This represents a significant advance in the reduction of the energy needed to build concrete structures and is therefore a sustainability issue. In addition *SCC* can offer benefits of up to 50% in labour costs, due to it being poured up to 80% faster and having reduced wear and tear on formwork. The material behaves like a thick fluid and is made possible by the use of polycarboxylates (a material similar to plastic developed using nanotechnology).

Fiber wrapping of concrete is quite common today for increasing the strength of preexisting concrete structural elements. Advancement in the procedure involves the use of a fibre sheet (matrix) containing nano-silica particles and hardeners. These nanoparticles penetrate and close small cracks on the concrete surface and, in strengthening applications, the matrices form a strong bond between the surface of the concrete and the fibre reinforcement.

Nanotechnogy and Steel

In steel, fatigue is a significant issue that can lead to the structural failure when steel is subjected to cyclic loading, such as in bridges or in towers. This can happen at stresses significantly lower than the yield stress of the material and lead to a significant shortening of useful life of the structure. Stress risers are responsible for initiating cracks from which fatigue failure results and research has shown that the addition of copper nanoparticles reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking.

When the tensile strength of tempered martensite steel exceeds 1,200 *MPa* then even a very small amount of hydrogen embrittles the grain boundaries and the steel material may fail during use. This phenomenon, which is known as delayed fracture, has hindered the further strengthening of steel bolts and their highest strength is limited to somewhere around 1,000 to 1,200 *MPa*.

Research work on vanadium and molybdenum nanoparticles has shown that they improve the delayed fracture problems associated with high strength bolts. This is the result of the nanoparticles reducing the effects of hydrogen embrittlement and improving the steel micro-structure through reducing the effects of the inter-granular cementite phase. As quoted in NSTR [3], instead of *CNTs* two relatively new products that are available today are Sandvik Nanoflex (produced by Sandvik Materials Technology) and $MMFX_2$ steel (produced by *MMFX* Steel Corp). Both are corrosion resistant, but have different mechanical properties and are the result of different applications of nanotechnology.

Nanotechnology and Coatings

In coatings, much of the work involves Chemical Vapour Deposition (*CVD*), Dip, Meniscus, Spray and Plasma Coating in order to produce a layer which is bound to the base material to produce a surface of the desired protective or functional properties. Research is being carried out through experiment and modelling of coatings and the one of the goals is the endowment of self healing capabilities through a process of "self-assembly".

Nanotechnology is being applied to paints and insulating properties, produced by the addition of nano-sized cells, pores and particles, giving very limited paths for thermal conduction (R values are double those for insulating foam), are currently available. This type of paint is used, at present, for corrosion protection under insulation since it is hydrophobic and repels water from the metal pipe and can also protect metal from salt water attack.

The remarkable properties of TiO_2 nanoparticles are being put to use as a coating material on roadways in tests around the world. The TiO_2 coating captures and breaks down organic and inorganic air pollutants by a photocatalytic process (a coating of 7000m^2 of road in Milan gave a 60% reduction in nitrous oxides) which may help in putting roads to good environmental use.

Nanotechnology and Glass

Fire-protective glass is another application of nanotechnology. This is achieved by using a clear intumescent layer sandwiched between glass panels (an interlayer) formed of fumed silica (SiO_2) nanoparticles which turns into a rigid and opaque fire shield when heated. Most of glass in construction is, of course, on the exterior surface of buildings and the control of light and heat entering through building glazing is a major sustainability issue. Research into nanotechnological solutions to this centres around four different strategies to block light and heat coming in through windows. Firstly, thin film coatings are being developed which are spectrally sensitive surface applications for window glass. These have the potential to filter out unwanted infrared frequencies of light (which heat up a room) and reduce the heat gain in buildings; however, these are effectively a passive solution. As an active solution, thermochromic technologies are being studied which react to temperature and provide thermal insulation to give protection from heating whilst maintaining adequate lighting. A third strategy, that produces a similar outcome by a different process, involves photochromic technologies which are being studied that react to changes in light intensity by increasing absorption. And finally, electrochromic coatings are being developed that react to changes in applied voltage by using a tungsten oxide layer; thereby becoming more opaque.

Nanotechnologies: Water Purification

Water purification using nanotechnology exploits nanoscopic materials such as carbon nanotubes and alumina fibers for nanofiltration. It also utilizes the existence of nanoscopic pores in zeolite filtration membranes, as well as nanocatalysts and magnetic nanoparticles. As indicated in Fig. 2, the adsorption of chlorine concentration is much higher by using nanotechnology (*GAC*, 350 g/m^2) as compared to conventional method of purification (*PAC*, 220 g/m^2)

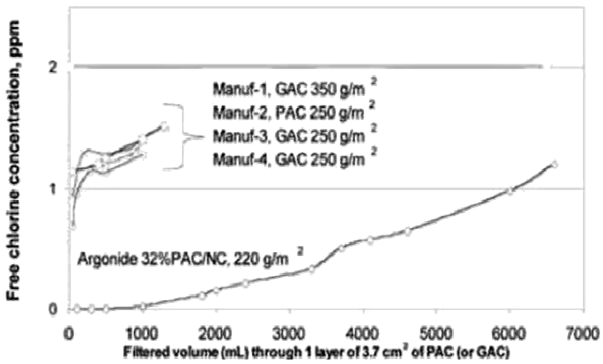

Fig. 2 Adsorption of chlorine by various media

Nanosensors, such as those based on titanium oxide nanowires or palladium nanoparticles are used for analytical detection of contaminants in water samples. It can be used for removal of sediments, chemical effluents, charged particles, bacteria and other pathogens. Valli et al [4] explain that toxic trace elements such as arsenic, and viscous liquid impurities such as oil can also be removed using nanotechnology". It is believed that future generations of nanotechnology-based water treatment devices will capitalize on the properties of new nanoscale materials.

Nanotechnology and Fire Protection and Detection

Fire resistance of steel structures is often provided by a coating produced by a spray-on cementitious process. Current portland cement based coatings are not popular because they need to be thick, tend to be brittle and polymer additions are needed to improve adhesion. However, research into nano-cement (made of nano-sized particles) has the potential to create a new paradigm in this area of application because the resulting material can be used as a tough, durable, high temperature coating. This is achieved by the mixing of carbon nanotubes (CNT's) with the cementious material to fabricate fibre composites that can inherit some of the outstanding properties of the nanotubes such as strength. Polypropylene fibres are also considered as a method of increasing fire resistance and this is a cheaper option than conventional insulation.

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What caused Kolkata flyover collapse?

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Figure 1: During casting period

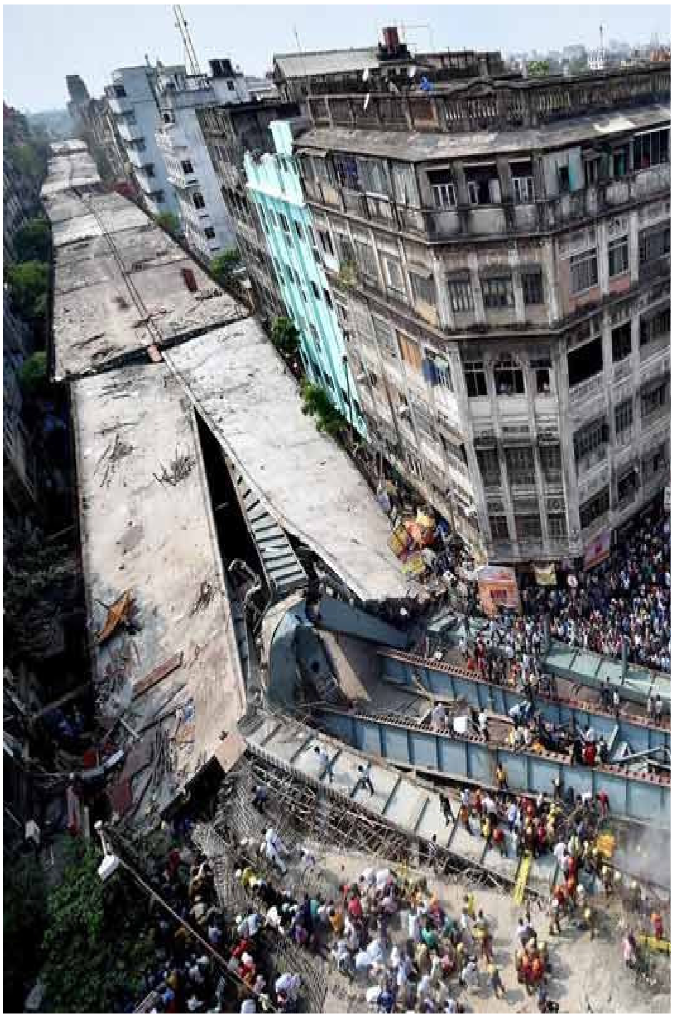

Figure 2: After collapse

Kolkata, 31st March 2016, Thursday afternoon, an under construction fly over collapses near Ganesh Talkies at Vivekananda road causing 24 deaths and around 80 others injured. The fatality could be more because at the time of collapse normal traffic was under operation just below the under construction bridge.

<u>The reason of collapse</u>: The super structure is a composite design. RCC deck is supported over steel girder. Such arrangement is very costly but most safe structure. Thus I don't think the superstructure (deck) failed. There was concreting in the previous day. Sometimes a portion of deck particularly cantilever portion collapses due to failure of temporary support such as brackets etc. But such collapse occurs when concreting work is in progress because wet concrete weighs more than set-concrete. (Wet concrete is 3000 Kg/Cum where as set concrete 2400 kg per cum). Initial setting takes place within 12 to 16 hours depending upon mix design.From visuals it's clear that the pier cap failed thus bringing down two spans supported over it. Failure of pier has many reasons.

<u>Design aspect</u>: It was known from the beginning that due to space constraint and traffic load, the fly over had to be constructed not restricting the traffic movement. Thus design has taken care of this aspect providing all steel structure (above pile cap all members such as pier, pier-cap and super structure are made of steel member). Steel structure is the safest structure although very expensive. Standard design are checked with STAADPRO and hence it can be concluded that there was no faulty design. Further all other spans were alright proving that this pier/pier cap had some problems.

<u>Execution aspect</u>: Standard Operating Procedure (SOP) of such execution always needs to ensure approved material sourcing, fabrication by expert workforce, pre-inspection and post inspection after assembling, thorough checking of everything in the checklist before any further load is applied. IVRCL is a reputed agency and the concerned government department too is expected to be non-compromising on quality issues particularly when it is being executed while traffic is allowed to move under it.

I believe that there must be some error of omission, which might have happened. After doing successfully most of spans sometimes mid level and junior level engineers becomes bit complacent. Thus inspection might be done casually omitting serious flaws either in joints of pier cap/pier or by mistake some unwanted eccentric loading being done due to piling up construction materials. These are called human errors.

COMPARATIVE STUDY BETWEEN DIFFERENT TYPES OF FORMWORK

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INTRODUCTION

Formwork by name means "The Mold" which means it is the casing into which the casting material, usually concrete, is poured to obtain the desired structural shape. In construction industry formwork is similar to a mold to cast concrete member in different shape and sizes using different types of materials such as timber, steel, aluminum, plastic, etc. Shuttering is a synonym term used for form-work. Form work should have sufficient strength to carry dead load and live load coming on it during casting operation and after that till concrete gets hard and gain some percentage of design strength.

TYPES

Various types of shuttering used in construction industry are listed below:

1. Timber Form work:

The Timber formwork is one of the mostly used in construction industry, fabricated on site using timber. It is easy to produce but time-consuming for larger structures. Plywood facing has a short lifespan. Timber is easy to fix, remove and lightweight. Timber Shuttering is most flexible type of shuttering; it can be used for any shape and size. Timber shuttering should satisfy the following requirement:

- Lightweight
- Well-Seasoned
- Free from termite attacks
- Easily Workable

Timber formwork in staircase construction

Advantages of using timber forms:

Timber Shuttering is easy to construct for any shape, size and height.

It is economical for Small projects.

It can easily be made into any shape or size.

It can be constructed using locally available timber.

It is light weight as compared to steel or aluminum Shuttering.

2. Plywood forms (in combination with timber):

Plywood is an artificially manufactured wooden material available in different thickness and size used in formwork for concrete member. It is strong enough, durable and light weight. Plywood is one of the mostly used materials for sheathing, decking and form linings in shuttering.

Plywood forms in combination with timber

3. Steel Formwork:

Steel formwork is now becoming popular due to its long life time and multiple time reuses. Steel formwork is costly but can be used for large number of projects. Steel shuttering give very smooth finishes to concrete surface. It is suitable for circular or curved structures such as tanks, columns, chimneys, sewer, tunnel and retaining wall.

Advantages of steel form-work over timber form:

Steel shuttering is strong, durable & has longer life.

It gives very smooth finish to surface of member.

It is waterproof and minimizes the honeycombing effect.

It can be used more than 100 times.

Steel formwork can be installed & dismantled with greater ease.

Steel formwork for RC Wall

4. Aluminum Form work:

Aluminum formwork is similar in many respects similar to those made of steel. Aluminum forms are lighter than steel forms due to low density and this is their primary advantage when compared to steel. The shuttering is economical if large numbers of repeating usage are made in construction. The disadvantage is that no alteration is possible once the formwork is constructed.

Aluminum Shuttering in Roof slab Casting

5. Plastic Formwork:

Plastic form work is a lightweight modular, interlocking system and can be used more than 100 times. It can be used for simple concrete structures. This type of shuttering is becoming popular for similar shape and large housing scheme.

Advantage of Plastic Form work:

It is light weight shuttering hence requires less handling cost.

It can be used for large section.

If carefully transported and used, multiple reuses are possible making it highly economical.

Plastic Formwork Concrete Wall

6. Fabric Formwork:

Fabric formwork is emerging technology in shuttering industry for construction of irregular shape and complex member. The flexibility of this material makes it possible to produce concrete at any shape.

7. Coffor Formwork:

Coffor is a stay in place formwork system. It is composed of two filtering grids which is reinforced by vertical stiffeners and linked by articulated connectors which can be folded to transport on site. Coffor remains in place after concrete is poured and acts as reinforcement. Coffor is transported to the site prefabricated from the factory. This type of shuttering can be used for any type of structure like houses, multistory buildings etc.

TYPES OF FORM WORK BASED ON STRUCTURAL MEMBER

1. Wall Form work:

Wall formwork used for concreting of shear or RCC wall in dams, wing walls, basement rcc walls etc. Wall shuttering made up of vertically arranged upright timbers (bearers) to which plywood sheeting boards are nailed at the inner side. The upright timbers are diagonally braced with the help of boards at both sides.

2. Beam Form work:

Beam is the most important member in RCC framed structure. Beam formwork has prefabricated form work includes sheeting bottom and side sheeting panels. The individual parts of form-work are manufactured based on the beam size. For prefabrication of the sheeting parts, a table for fabrication must be manufactured on site.

3. Foundation Form work:

Foundation formworks designed according to foundation type. Shuttering design for foundation depends on foundation type like footing, combined footing, raft. Basically there is a difference in the design for individual foundations, and shuttering for strip foundations. The design of shuttering is dictated by the size, mainly by the height of the foundation.

4. Column Formwork:

Formwork arrangement for column may differ on the basis of column outline like rectangular, circular, and hexagonal or any other shape. The sheeting of column shuttering is constructed

according to the column dimensions. The panels are placed in a foot rim, anchored in soil with the help of bolts.

FORMWORK STRIKING PROCEDURE

Ease all supports by 1-2 turns for each prop

Starting from mid-span, remove the props towards columns or walls

This will ensure no negative hogging bending moment induced in the concrete slab if the last few supports were left at the mid-span as intended in the original design.

Cracking due to reverse bending will occur otherwise .

Conclusion

After detailed study about formwork we have come to know that there are various types of formwork which are functionally same but it has a great impact on economy i.e on the cost of the project. If we use aluminum formwork , it can be used several tymes with the benefit of reduction in cost of use in each time. A rough estimate of cost deduction for the use of several times given below

Number of uses	Cost per square foot of contact area
1	1.00
2	0.62
3	0.50
4	0.44
5	0.40
6	0.37
7	0.36
8	0.34
9	0.32

Though the initial cost is very high but alumina shutter is more and more economical than others.