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Investigation on the Use of Sosrobahu Technology as Road Construction Technique

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Abstract

In order to minimize traffic disturbance during the construction of flyover, the 450 tones pier head is turned 90 degrees. A device is used in Metro Manila Skyway Project in the Philippines. The Sosrobahu device is a hydraulic non friction rotating device; it is a flat jack with a diameter of 80 cm and place in the center of pier. The pier head is then cast over the pier parallel to road axis, oil is injected into the device until the force produced but the oil pressure nearly equals the weight of the pier head, then the pier head is turned 90 degrees. Oil pressure is then released and the gap injected with non-shrink grout. Four post-tensioned U cables of total ultimate capacity of 600 tones are then turned through the pier head and pier, post-tensioned and grouted.

Keywords: *Elevated roadway, skyway, sosrobahu, transportation engineering*

1. Introduction

The Metro Manila Skyway project has been designated by the government as one of its priority flagship projects, largely due to its positive economic factors. The project aims to provide a vital link between Metro Manila and the regional growth centers in both the northern and southern areas of Luzon through an elevated expressway system connecting the South and North Luzon expressway from Alabang to Balintawak via the inner western corridor of Metro Manila. The project is to boost the conduct of trade and commercial activities. Likewise, it's aims to promote the development of a corridor that leads directly Metro Manila's financial centers in Makati City.

Present demand of over 200,000 vehicles per day along South Superhighway is suppressed by lack of capacity. The expansion of this corridor by the elevated highway is to relieve daily traffic congestion that now prevails in the area.

The project is a 6-lane facility from Alabang to Balintawak consisting of 33.68 kilometers of an elevated expressway and 1 kilometer at grade expressway fronting Runway 6-24 of The Ninoy Aquino International Airport for a total distance of 34.68 kilometer. It includes the rehabilitation of the existing South Luzon Expressway from Alabang to Magallanes with a distance of 13.43kilometer [1].

The first stage of the Skyway System consists of the construction of the 9.5-kilometer elevated road from Bicutan, Parañaque City to the Makati Central Business District as well as the rehabilitation of the 13.5-kilometer section of the South Luzon Expressway from Alabang to Magallanes.

When Skyway Stage 1 first opened to traffic, an average of 160,000 vehicles per day used the Skyway System—around 25,000 on the elevated and 135,000 on the at-grade—

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with these numbers increasing in subsequent years. Millions of commuters now use the Skyway System every day, and they have all benefited from the concrete benefits of the completed project [2].

Before the Skyway System, a trip from Alabang to Magallanes took about two hours on the average. With the Skyway Stage 1 in operation, it now takes only 30 minutes or less to travel on the Alabang-Magallanes at-grade section and less than 15 minutes on the elevated section. Motorists have also been enjoying the excellent road condition, expert traffic management, less pollution and no flooding on the Skyway System.

As shown in Figure 1, Skyway Stage 1 has already afforded thousands of motorists' enormous savings slashing travel time from the snail-paced southern arteries to the Makati Central Business District by as much as 50%.

Figure 1. Skyway stage 1

The South Metro Manila Skyway Project Stage 2 consisting the 6.88 kilometer elevated expressway from Bicutan to Alabang that extends the 9.5 kilometer elevated toll road from Makati to Bicutan known as the Skyway Stage 1.

Skyway Stage 2's Bicutan-Sucat section boasts of six wide travel lanes with four lanes at the Sucat Ramp Toll Plaza leading westward to Dr. A. Santos Avenue shown in Figure 2. The Sucat-Alabang Section has four travel lanes from Sucat going down to the two-lane slip ramps leading to the South Luzon Toll way in front of Hillsborough Subdivision [3].

Figure 2. Bicutan-Sucat section

The Main Toll Plaza situated between Sucat and Alabang has six lanes on each direction shown in Figure 3. It will replace the temporary Skyway Toll Plazas near the East Service Road at the NAIA flight path.

Figure 3. Main Toll Plaza section

The Alabang Northbound Entry Plaza, meanwhile, has two lanes-one leading to the Skyway's elevated section and the other to the at-grade section shown in Figure 4

When completed, this infrastructure is expected to allow a quick breeze on the elevated toll road from the Alabang Toll Plaza to the Buendia off Ramp in only 12 minutes at the speed of 80kph [4].

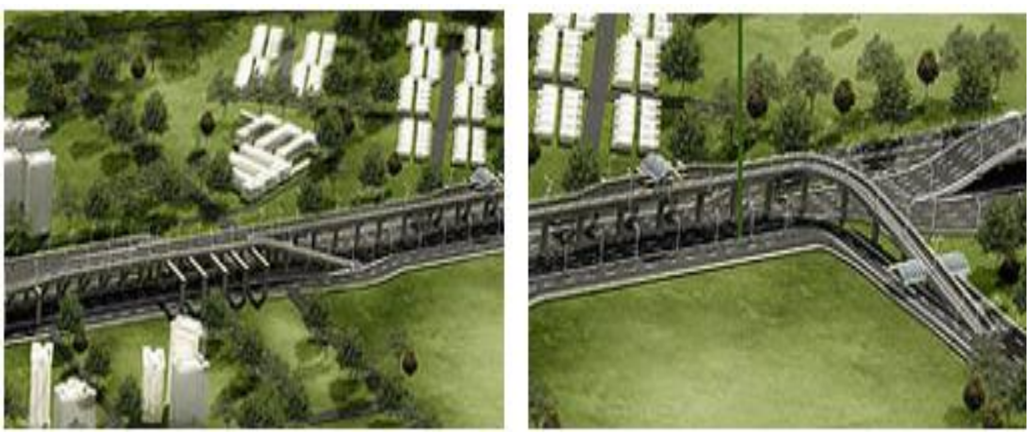

Figure 4. Alabang section

2. Sosrobahu Mechanism

2.1. Origin

By the 1980s, Jakarta was experiencing increased traffic congestion, and flyovers were seen as one solution to the improving transport infrastructure. One construction company operating at that time was PT Hutama Karya, which was granted a contract to build a highway above bypass A Yani, an extremely important stretch of highway where it was vital that the road would continue to be open to traffic throughout the period of construction [5].

In addition to this challenge, PT Hutama Karya was also granted a contract to build a flyover between Cawang and Tanjung Priok. The most difficult issue was the requirement to support the road with a row of concrete pylons (pier shafts) 30 m apart, on top of which would sit the 22 m wide road supports. The vertical pier shafts were to be hexagonal in shape with a diameter of 4 m, and were to sit in the central lane of the existing road. The erection of the pier shafts was not difficult; what caused problems were the poured concrete pier heads. With conventional construction techniques, the pier heads would be moved into place with the help of iron supports beneath the outspread pier heads, but the use of iron supports would necessitate the closure of the road below. Another option was to support the pier heads from above, but this increased the costs of the project.

In response to these problems, Sukawati had the idea of initially erecting the concrete pier shafts and then building the poured concrete pier heads in the center lane, parallel to the existing roadway, and then raising and turning the pier heads 90 degrees into place. The only problem with this idea was that the pier heads weigh approximately 480 tons each.

The new technique had not yet been trialed because of time constraints, however Tjokorda was certain that it would work and was willing to bear the responsibility should the concrete pier heads not be able to be turned 90 degrees as required for the construction of the flyover.

The hydraulic pump was pressurized to 78 kg/cm². The pier head, despite lack of iron supports, was lifted and placed on top of the pier shaft and then with a light push was turned 90 degrees into its final position. The oil was then slowly pumped out and the pier head was lowered onto the shaft. The LPBH system was then shut down as it required heavy machinery to move it. Because he was worried that the single pier shaft and head might shift for a lack of support, he propped them up with eight concrete supports, 3.6 m in diameter. The LPBH was then used to raise the other pier heads over their respective shafts [6].

President Suharto of Indonesia gave the name Sosrobahu to the new technology. The name was taken from a character in the Mahabharata, and derives from Old Javanese for thousand (sosro) shoulders (bahu).

Tjokorda's invention was used by US engineers in the construction of a bridge in Seattle. They placed the oil under a pressure of 78 kg/cm² as per Tjokorda's original theories. Tjokorda himself wanted to investigate further the limits of his invention and built himself a laboratory where he successfully tested the LPBH to a limit of 78.05 kg/cm².

Patents have been granted for the invention from Indonesia, Japan, Malaysia, and the Philippines, and have been applied for in South Korea. The Indonesian patent was granted in 1995, while the Japanese patient was granted in 1992. The technology has been exported to the Philippines, Malaysia, Thailand and Singapore. The longest stretch of overpass built using this technique is in Metro Manila, Philippines at the Villamor/Bicutan link located at the southern part of the metropolis. In the Philippines, 298 supports have been erected, while in Kuala Lumpur, the figure is 135. When the technology was introduced to the Philippines, the President of the Philippines, Fidel Ramos commented: "This is an Indonesian invention, but is also an ASEAN invention".

A second version of the technology has been developed. Whereas the first version used a steel anchor inserted in a concrete base, the second version uses a single plate with a hole in the middle which is not only simpler, but also significantly speeds up the time it takes to erect a pylon from 2 days to 45 minutes. It is expected that the lifespan of flyovers constructed using the Sosrobahu method will be approximately 100 years.

According to Dr. Drajat Hoedajanto, an expert from the Bandung Institute of Technology, Sosrobahu is a very simple solution to the problem of erecting flyover pylons and is suitable for use in the construction of elevated toll roads which have traffic running underneath them. Sosrobahu is clearly a useful and versatile technology

2.2. Technical aspects

Unique in this aspect is the introduction of a technology for the construction of elevated roadways with single piers directly over existing busy roadway known as the Rotating Pier Head technology. The main purpose of which is to mitigate traffic disruption during construction. Normal casting of the pier head across the roadway will require a wide construction area due to the scaffoldings. Similarly this method of recasting the pier head on ground and lifting operation notwithstanding the dangers of such an operation. The Rotating Pier head technology allows for the concreting in place of the pier head initially parallel to the roadway with nominal encroachment into the existing roadway, and then rotated into its final position after the concrete has attained adequate strength.

The rotating of the pier head is made possible by a simple rotating pier device, invented by Engineer Tjokorda Sukawaki of Indonesia [4,7]. This device, locally known in Indonesia as "Sosrobahu", literally meaning a "thousand shoulders", consists of two disk-like structural steel mechanisms fitted together and rotates in a manner similar to turntable shown in Figure 5.

Figure 5. Rotating pier head

This rotating device is placed between the pier column and the pier head. Controlled hydraulic pressure is introduced between the two discs like mechanisms, acting essentially as a flat jack, until the uplift force is almost equal to the weight of the pier head. At this stage, the pier head is somewhat, " floating exercised in injecting oil pressure such that the force does not exceed the weight of the pier head in which case the head literally "floats on oil" shown in Figure 6. A critical unstable condition of the pier head is reached and shifting of its weight could cause tremendous pressure on the walls of the steel device which may cause its collapse [8,12].

Moreover, this technology is used for building an elevated toll road above the existing road which is already in full operation. The pier head that supports the beams, which is 25 meters, is wider than the existing road, which is 19 meters. Using the conventional method of casting the pier head across the existing road would hamper the traffic.

The pier is built in the median between the roads. Then the pier head is cast parallel with the existing road and separated with the pier. The innovative equipment is put between the pier and the pier head before the reinforcement and concrete of the pier head are placed.

Figure 6. Sequence installation of sosrobahu mechanism

A U-shaped cable duct was placed in the pier through which the prestressing cable will be inserted later, after the concrete of the pier head is strong enough to hold its own weight. Then the pier head is turned by pulling with 800 kg forces until it is perpendicular to the axis of the existing road. The weight of the pier head is about 450 tons. In Kuala Lumpur where the same technology is used, the weight of the pier head is 540 ton. The innovative equipment is left there forever [4, 9].

After grouting the space between the pier and pier head, which is 2.50 cm, with grouting material for prestressing, the prestressing cable is then inserted through the cable duct. There are 4 cable ducts on each side. In every cable duct, 4 to 6 prestressing wires 0.5" thick are inserted and given prestressing forces of 200 ton on each side. After that the duct is then grouted. The pier head is then ready for supporting the beams. During the construction of the pier, the traffic at the existing road was in full operation.

The device of the rotating mechanism is based on the Torque Formula of Beer and Johnson Jr and modified by Engineer Sukawati using Pascal's law [10, 13].

Beer and Johnson Formula

$T= \mu N2/3(R_1^3-R_2^3)/ (R_1^2-R_2^2)$

where T = Torque required for rotation

μ = Coefficient of viscous friction

N = Normal force acting on the rotating device

R_1 = Inner radius of the rotating device

R_2 = Outer radius of the rotating device

It seen that for given dimensions of the rotating device, the torque is directly proportional to the coefficient of friction and the normal force N, which in this case, is the weight of the rotating body. To reduce the normal force, an uplift force is introduced by injecting pressurized oil in between the two rotating mechanisms shown in figure 7, thus, the Torque formula is modified by the equation

$T= \mu (W-P)\ 2/3(R_1^3-R_2^3)/(R_1^2-R_2^2)$

where W = Weight of the rotating body

P = Uplift force due to pressure p

As shown in figure 6, the Sukawati Formula is modified as

$T_r = km\ (W-P)\ 2/3(R_1^3-R_2^3)/(R_1^2-R_2^2)+2MR_2/h$

$T_r = KL;\ P = 0.785\rho\ R_1^2$-

where M = Moment in kg-cm

K = Pulling force in kg

L = distance between the central point of rotation

K = pulling force

ρ = kg/cm^2 (oil pressure)

Above the critical oil pressure the torque suddenly becomes so big that rotation becomes impossible. The critical oil pressure is different for every weight and oil that is used for the uplift inside the equipment.

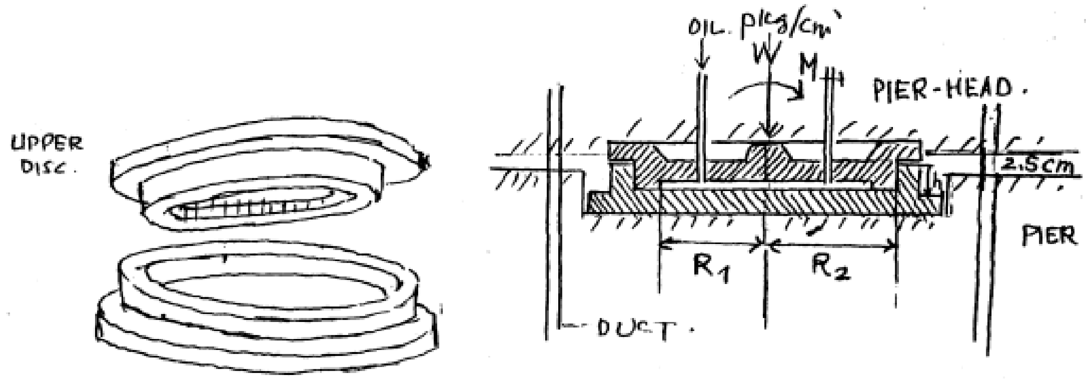

Figure 7. Illustration of the equipment

During rotation, friction is developed from three sources, i.e., viscous friction from contact with the oil, at the contact area of the two steel plate mechanisms and at the peripheral contact point between the rubber seal and the walls of the lower steel plate. However, the rubber seal friction is very small and may be neglected.

Extensive tests of actual prototypes of a rotating pier head were conducted to validate the sheer simplicity of the theoretical basis used in developing the rotating device. Factors such as the type of oil to use, the type of rubber seal to contain the oil pressure and prevent leakage and the speed of rotation to prevent the development of extreme temperature on the oil medium, were studied. Only after the inventor was convinced of the satisfactory performance of the rotating device was it finally used in the actual construction in Indonesia [4, 11, 14].

After rotation, the oil pressure is released and the pier head is locked permanently to the column by post-tensioned cables designed to resist unbalanced loading due to live loads and grouted supplementary steel anchor dowels designed to resist earthquake shear forces.

Additionally, the superstructure is constructed essentially from the deck level. Girder launchers equipped with mobile overhead cranes are erected on top of the pier heads that pick precast prestressed concrete girders directly from delivery trucks and position them in place. Precast concrete panels designed to resist positive live load moments are laid out over the girders to act as formworks during construction and act compositely with the cast in place deck slab at working loads.

2.3. Installation of sosrobahu

2.3.1. Stage 1: During construction of the column head: Install sheath and anchorage, check the position and protect holes.

2.3.2. Stage 2: After the construction of the column head: Install the sosrobahu device with upper and lower nuts to control the center point and level and grout the sosrobahu bedding through inlet and outlet pipe. This is done after the pier head was rotated

2.3.3. Stage 3: Fill the 20mm gap between column and pier head: Record the exact position of the U-strand and install 6 mm plywood, spread sand 10mm thick and then install 6mm steel plate. Plot the marking of the U-strand positions on the steel plate.

2.3.4. Stage 4: During construction of the pier head: Install hydraulic inlet, outlet pipe, sheaths of U-strand, hook level, inlet and outlet pipes for grouting the 22 mm gap

2.3.5. Stage 5: After the construction of the pier head: Remove the 22 mm gap dilation, blow sand and pull out steel plates and plywood. Clean the gap thoroughly.

2.3.6. Stage 6: Rotating the pier head: Pre-mark the position of rotated pier head on the column top; Install the hydraulic pump and connect the wire rope to hook level; Rotate the pier head by pulling smoothly until the pier head and column are matched each other; Release the hydraulic pressure and insert the strand into sheath; Grout the 22 mm gap; and Prestress the strand and grout the sheath duct.

2.4. Construction procedure in Metro Manila Skyway

The construction of an elevated expressway along the South Luzon Expressway, which carries above 200,000 vehicles per day, required an innovative form of construction to avoid exacerbating the existing problems of slow moving or standing traffic during peak hours. The adjacent roads are also extremely congested and thus diversion routes limited [4, 5].

As shown in Figure 7, the construction method chosen utilizes a rotating pier head and was originally formulated in Jakarta where similar traffic problems exist and generally follows the following procedure:

a). Widening of the existing carriageway within the right of way, erection of a traffic barrier one lane either side of the central medium or piling of the foundations (all works taking place within this boundary).

b). Excavation and construction of pile cap and column including U ducts cast in sockets for dowels, and box out for the rotation device.

c). The rotating bearing device or sosrobahu is then precisely installed and grouted. Joint filler is placed to form a 20mm gap between the concrete faces from the top of the column and the pier head formwork constructed parallel to the road axis.

d). Reinforcement is fixed and the pipe head concreted. After reaching the required strength is a post-tensioned along its length.

e). The rotating device is then injected with hydraulic fluid to just support the weight above and the pier head swung through 90 degrees. Dowel bars are located between the column and pier head and the hydraulic fluid released to allow the pier head to be seated at right angles to its original position.

f). Prestressing strand is then inserted into the pier head, through the U ducts cast in the column and back into the pier head. After strand is inserted into all four similar ducts the pier head/Colum connection is stressed and both the gap and duct grouted.

g). Presstressed I beams (AASHTO type V) produced in the casting yard are then erected by crane or launching gantry. Precast concrete slabs which span between the beams are placed onto the beams, reinforcement fixed and the deck cast

Figure 8. Construction procedure in Metro Manila Skyway

3. Conclusion

The Metro Manila Skyway serves a reliever facility to the South Luzon Expressway project which is the main artery to the province and cities of South Metro Manila. From a spatial standpoint, the municipalities of Paranaque, Alabang and Muntinlupa and several Laguna towns are within immediate service coverage of the said project. As Metro Manila grows, they are becoming the sites of new housing and industrial project by accommodating the bargaining demand for residential and industrial space. Within the next few years, it is expected that the province of Laguna, Cavite and Batangas will become increasingly industrialized. All these development translate into the rapid growth of vehicular traffic using these facilities.

Also the project is the expansion of the heavily utilized Alabang to Buendia corridor where 170,500 vehicles pass through every day. This corridor is a critical link between the country’s main urban center and its main industrial heartland. When the corridor is expanded by the skyway, it is projected that it can accommodate over 300,000 vehicles per day by the end of the decade.

It may be said that the greatest contribution of the Sosrobahu lies in its economic merits in that the need for costly acquisition and development detour routes during the construction works is vastly reduced if not totally eliminated.

While the methodology used in these projects can be considered ordinary by some more advanced countries in the world, it is worth mentioning that CMMTC coped with the schedules set with delays incurred.

Moreover, the public is rest assured that with the more stringent requirements of the present seismic design code, the integrity of the skyway structure is well above those of other similar structures designed and constructed in the 90's which have withstood the strongest earthquake so far experienced inside Metro Manila

References

[1] I. Dipohusodo, "Manajemen Proyek & Konstruksi", Jilid 1, Kanisius, **(1996).**

[2] P. Ngoc-Phuong, "An Evaluation Methodology for Laying Pattern of Interlocking Concrete Block Pavements Using a Displacement Moment Concept", Journal of Transportation Engineering, **(2013).**

[3]J. Kristanto, 1000 Tahun Nusantara, Kompas, **(2000).**

[4] T. U. Ganiron Jr, S. Amjid, R. D. Castro, R. Bantolo and M. Munir, "Metro Manila Skyway: It's Effect on Environment, Traffic and Population", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(1997).**

[6]H. Indarto, "Analisis Struktur III", Kanisius, **(2007).**

[7] T. U. Ganiron Jr, "A Practicum Report in Metro Manila Skyway Projects (Stage 1-Buendia to Bicutan), Master's Project, Civil Engineering Department, De La Salle University, Manila, **(1997).**

[8] S. Islam and S. Brown, "Transportation-OPOLY: An Innovative Tool to Promote Transportation Engineering", International Journal of Traffic and Transportation Engineering, vol. 2, no. 3, **(2013).**

[6] T. U. Ganiron Jr, M. I. Laman, A. Climacosa, R. Ayeng and R. Mariano, "Efficiency of Sosrobahu Mechanism for the Construction of Elevated Roadways with Single Pier", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(2000)**.

[7] A. Balaan, C. Abaya, R. Dayrit, R. Vergara and J. Condeza, "Formulation of Precast High Strength Concrete as a Solution to Fast Track Projects", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(1998).**

[8] T. U. Ganiron Jr, J. Aparato, M. Abayon, M. Baybay and R. Sison, "A Study on the Development of Skyway Systems (Phase 2: Nichols Toll Plaza to Bicutan): Its Trends and Impact to the Commuters", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(2000).**

[9] S. Rutledge, "Repair of Reinforced Concrete Bridge Columns Containing Buckled and Fractured Reinforcement by Plastic Hinge Relocation", Journal of Bridge Engineering, **(2013)**

[10] T. U. Ganiron Jr, V. Flores, R. Uaje, M. Lucenada, J. Boboyo and R. Dizon, "A Study on the Developmental Impact of the Proposed Interchange to Minimize the Worsening Congestion along the Zapote- Aguinaldo Highway Intersection", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(1999).**

[11] B. Mei, "A Review of Durability Research of Concrete Bridge", Applied Mechanics and Materials, **(2013).**

[12] F. Sol Jr, S. Banzuela, J. Ave, F. Seville and R. Joson, "An Assessment in Construction of Underground Railways along Edsa corner Ayala Avenue to Pasay Road", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(2000).**

[13] T. U. Ganiron Jr, M. Velante, J. Sam and K. Yuipco, "A Study on Accessibility of a Road Network Development of BF Home Paranaque and Along Sucat Road", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(2000).**

[14] F. Sol Jr, G. Torres, N. Cortes, F. Samson and E. Torres, "A Study of Inefficient Traffic System along Taft Avenue from Vito Cruz to Libertad Street", BS Thesis, Civil Engineering Department, FEATI University, Manila, **(2000).**

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