# Bangkok International Trade and Exihibition Center: large-scale suspended roof

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# Bangkok International Trade and Exhibition Center: Large-Scale Suspended Roof

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## Summary

This report shows the structural design and the construction process of large roof (about 35,000 $m^2$ area covered) which is suspended by masts and tie-rods system. BITEC (Bangkok International Trade & Exhibition Center) has a large scale exhibition hall which was built in Bangkok city and was completed in July 1997. In this building, we have employed the suspension structure for indoor exhibition hall to obtain no column space over 20,000$m^2$ . Suspended roof is composed of seven parallel frames which are laid side by side at the distance of 27m. Each frame has two main steel masts standing on the reinforced concrete columns, one main steel truss girder covering 100m span, reaction beam (36m long) at the outer sides of both columns and high-strength tie-rods for suspending girders and beams.

## 1. Introduction

In Bangkok, capital of Thailand, the BITEC (Bangkok International Trade and Exhibition Centre) was constructed as the international exhibition center capable of sending information to the world through all available media. The BITEC was built at a distance of about 8 km from the center of city, along highway stretched toward the east from Bangkok, ensuring easy access from Don Muan International Airport through highways and from hotels in the city.

BITEC is a large scale exhibition center which has 20,000 $m^2$ indoor exhibition hall, meeting facilities, restaurant, etc. So as to realize no-column space in the large scale indoor exhibition hall, the suspension structure was adopted. The steel frame truss type mast and tie rods are used to suspend a large roof (100 m in span direction, 200 m in beam direction).

Figure 1 shows the outline of plot plan having an area of about 240,000 $m^2$. One heliport, outdoor exhibition zone, outdoor park, pond, green space, etc. are located around the outdoor exhibition zone. Table 1 shows the outline of buildings. Photo 1 shows the whole view of buildings and Figure 2 shows cross-section. The 2nd and 1st basements are mainly used for machine room and indoor parking for about 1,500 cars. On the first floor, entrance, restaurant and loading area are located around the indoor exhibition hall which serves as a main hall. The main hall can be used as an open space having the area of max.100m x 200m. As the effective height under beam is 15 m and the live load of floor is 1.0 t/$m^2$, it can exhibit long and heavy items. On the 2nd floor, convention hall (1800$m^2$) and other meeting rooms are located. The construction was completed on July 1997.

The basic design of BITEC was made by the major Thai designing offices Design 103 (architectural design) and ACS (structural design). For the conceptual design made by Design 103, the three companies, Thai Konoike, NKK Corporation and Tomoe Corporation made the technical proposal, and we have received an order including detailed design and construction. The major points of technical proposal are the application of the designing and construction process which simplifies the details by applying tie rods for the suspending members of large-scale suspension roof and ensures the specified construction accuracy by repeating simple works, and the adoption of "Self-balancing system" to avoid transmitting large lateral force to lower structure, which are columns and foundation made by reinforced concrete.

## 2. Structural system

The structural system of BITEC consists of reinforced concrete lower structure, steel frame general roof (minor roof truss) and large-scale suspension roof (main roof truss) of exhibition zone.

In Thailand which has tropical monsoon climate and is located on the stable Eurasia continent, the dominant load is not lateral load such as seismic load or wind load but vertical load. Table 2 shows the load conditions for structural design. We considered also the temperature load in addition to own weight, live load, and wind load. The dead load of the large roof, including the heat insulating and sound absorbing insulation board and facilities load, was 180 kg/m$^2$. Besides, the suspended load (2 t/place) on the 9 m grid was taken into account for the whole large roof surface as additional load.

Figure 3 shows the image of structural system. The lower structure supporting the main roof is made of reinforced concrete. Especially, the RC column under the main column suspending the large roof of indoor exhibition hall has sufficient strength and stiffness. For the part lower than the 1st floor slab, the flat slab based on 9m x 9m grid is used.

For the roof frame of the building, one element (one bay) consists of two main columns facing each other, main truss (3 pieces compose one assembly, and it has 100m span), reaction beam at both ends and suspending member (tie rod). Seven bays are arranged in the beam direction to form the large main roof.

Figure 4 shows reaction mechanism. The vertical load applied to the main truss is suspended from the top of main column as tension of T3 and T4 tie rods. This tensile force is carried by tension of T1 and T2 tie rods and transmitted to the lower structure through the anchorage buried in the block. At this time, the axial force of main column is about 540t, and the drawing force affecting the anchorage is 210t.

In the case where such an external cable suspension structure is adopted, treatment of lateral force which occurs in the peripheral frame is a problem to be solved. The building is designed so that the left and right thrusts are offset to realize the self-balancing system by arranging the reaction beam outside the column and only the drawing force is transmitted to the lower structure.

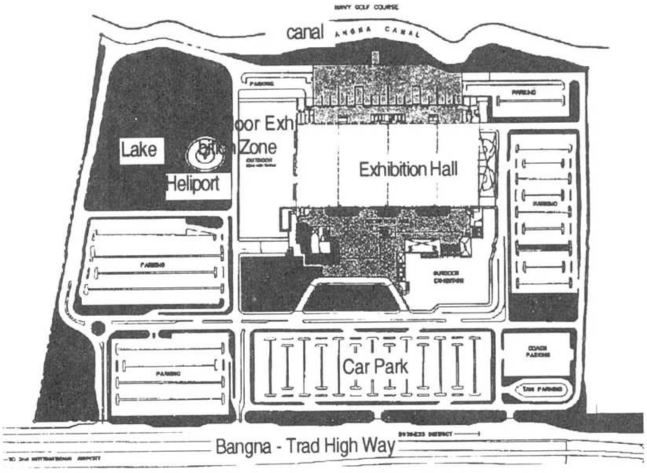


*Figure1: Plot plan*

*Table 1: Outline of the design*

| | | |
|---|---|---|
| Project Name | Bangkok International Trade and Exhibition Center (BITEC) | |
| Building site | Bangna-Trad Highway 1km, Prakanong, Bangkok,Thailand | |
| Client | Parinthorn Co.,Ltd. | |
| Design | Architecture | Design 103 Co., Ltd. |
| | Engineer | ACS. Co.,Ltd. |
| | -Roof Structure | Thai Konoike Construction,NKK Corporation and TOMOE Corporation |
| Supervisor | Management 103 Co., Ltd. | |
| Constructor | Thai Konoike Construction Co., Ltd. | |
| Num. of Stories | Under ground 2F and 2F | |
| Building Area | 59,788.0m$^2$ | |
| Total Floor Area | 126,000.0m$^2$ | |
| Site Area | 240,000.0m$^2$ | |
| Const. Period | August, 1995 - July, 1997 | |
| Height | Each floor | B2F 3.85m, B1F 4.30m, 1F 6.50m |
| | Max. eaves | 23.0m |

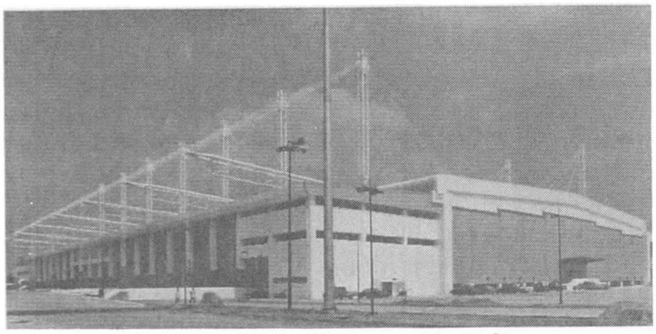

*Photo 1: Overall view of building*

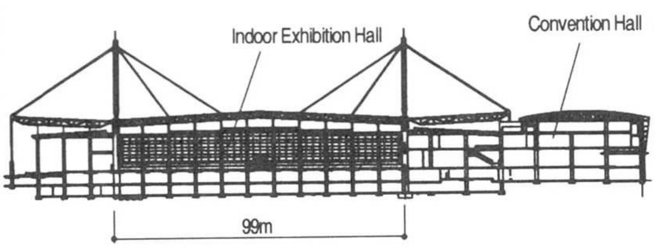


*Figure 2: Cross-section of building*

*Table 2: Outline of load conditions*

**Dead Load (DL)**

| | |
|---|---|
| Roof Self Weight | |
| Metal Sheet, Purlin | 10kg/m$^2$ |
| Steel | 90kg/m$^2$ |
| Ceiling (Including Insulation) | 30kg/m$^2$ |
| M & E Equipment | 50kg/m$^2$ |
| Total | 180kg/m$^2$ |
| Owner's Requirement Load, 2t/point x 210 points | |
| Main Column | 700kg/m |
| Reaction Beam | 700kg/m |

**Wind Load (WL)**

120kg/m$^2$

**Thermal Load (TL)**

Air Conditioned Case Indoor 25°C Out door 38°C (TL1)

No Air Conditioned Case Indoor 38°C Out goer 38°C (TL2)

Standard temperature 25°C

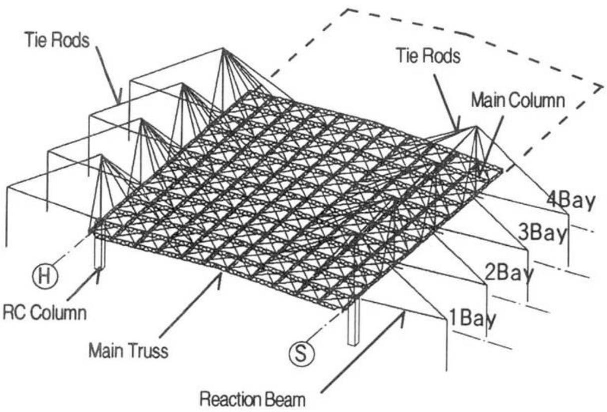


*Figure 3: Structural system of main roof*

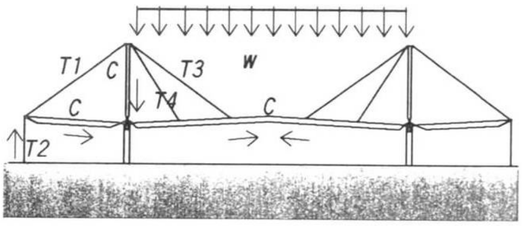


*Figure 4: Reaction mechanism*

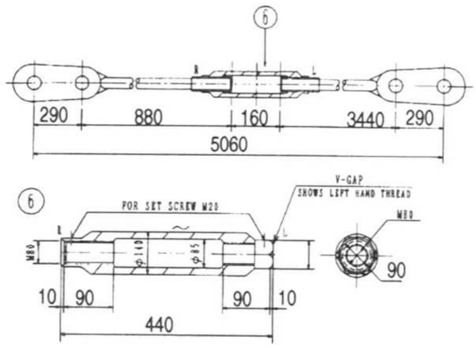


*Figure 5: detail of tie rod*

## 3. Structural components

### 3.1 Tie rod

The suspension structures have conventionally used cables as suspension members. In the case of BITEC, the high strength steel of HT690 class (tensile strength about 690 N/mm$^2$) is used as suspension member (tie rod). The mechanical properties of tie rod are shown in Table 3. The allowable stress of tie rod is specified as 1/3 of ultimate strength or 1/2 of yield strength, according to the Japanese structural regulations[1),2)]. We selected the tie rod with allowable stress of 220 N/mm$^2$. The tie rod has threaded end. It is jointed by using the coupler to get the specified length accurately. Figure 5 shows an example of the detail of the joint. Diameter of tie rod used for this building is 90 to 28 mm.

The tie rod has the following advantages compared to the cables.

1) Unlike cables, there is no need to apply pre-tension, so that the detail of joint can be simplified, thereby affording an advantage in cost. Since it has insignificant bending stiffness, it excels also in handling.

2) Unlike cable made by twisting several wires, the tie rod is steel bar characterized by low relaxation which is advantageous for length control.

3) Although the cable has higher strength, the tie rod of HT690 class is applicable to large-scale frames.

### 3.2 Main column (masts) and reaction beam

Figure 6 shows the joint detail of main column and reaction beam.

The main column is an assembly composed of 4 steel pipes. Tensile force of tie rod is transmitted to the lower structure as compressive force of main column. The length of the column is 36 m, and the size of main member is $\phi$ 355.6 x 12.7. The pin support is used for the column base. Even when

*Table 3: Mechanical properties of tie rod*

| Name of Material | Code No. | Yield point | Tensile Strength | Elongation | Remark |
|---|---|---|---|---|---|
| High tensile Steel | NHT690 | ≧440N/mm$^2$ | ≧690N/mm$^2$ | ≧20% | |
| Rolled steel for welding structure | SM460A | ≧315N/mm$^2$ | 490 ~610N/mm$^2$ | ≧21% | JIS G 3106 |
| Carbon steel for general structure | S35C | ≧305N/mm$^2$ | ≧510N/mm$^2$ | ≧23% | JIS G 4051 |
| Rolled steel for general structure | SS400 | ≧245N/mm$^2$ | 400 ~510N/mm$^2$ | ≧21% (Under 5mm) ≧17% (5~16mm) | JIS G 3101 |
| Stainless steel | SUS304 | - | 560 ~10N/mm$^2$ | ≧20% | JIS G 4315 |

elongation and shrinkage of tie rod occur, secondary stress such as bending does not occur. If the tie rod loses tension, stability is impaired. Accordingly, it is necessary to fix surely the main column with tentative fixing wire when the building is constructed.

The reaction beam is a truss composed of three round pipes. It protrudes at both sides from the left and right column bases. The length of member is 36 m, and size of main member is $\phi$ 457.2 x 16 and $\phi$ 216.3 x 12.7.

### 3.3 Other components

A support, called the embedded column, is embedded at the top of reinforced concrete column where the column, reaction beam and main truss are assembled. All the joints of this embedded column and each member use pin support which is designed so that only the axial force is transmitted. Photo 2 shows the assembled state of embedded column.

The main truss composed of H or L shaped steel is a truss frame having depth 2 m and span 99 m. Adjacent three pieces compose one bay. Two points of a truss are suspended from the left and right columns. Namely, 4 points of a truss are suspended by using tie rods.

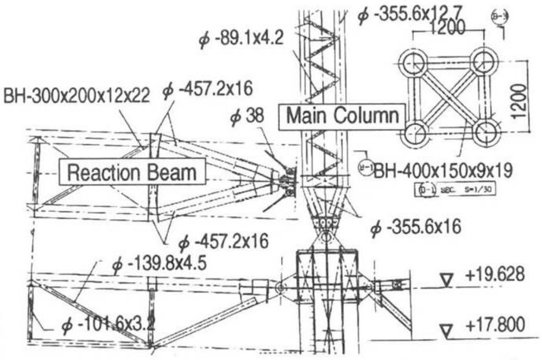


*Figure 6: Joint detail of column and reaction beam*

## 4. Construction

### 4.1 Painting

In view of typical climate of South-East Asia, namely high temperature and high humidity in rainy season, the inorganic zinc paint was used as primer, the epoxy paint was used for second coating, and the polyurethane paint was used for final coating. And epoxy paint was used for corrosion inhibition of indoor steel frame.

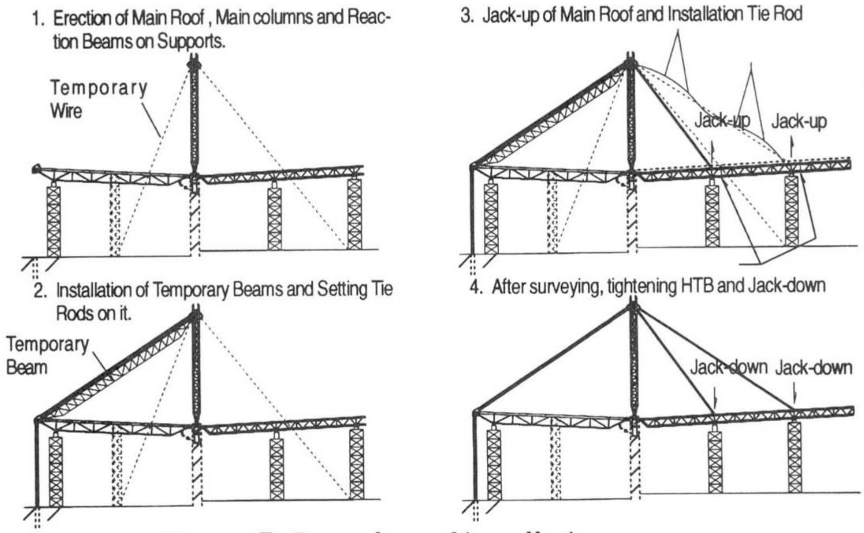


*Figure 7: Procedure of installation*

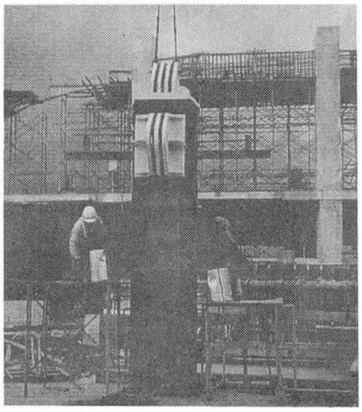

*Photo 2: Assembly of embedded column*

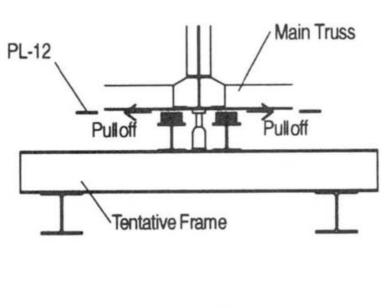


*Figure 8: Jack down process*

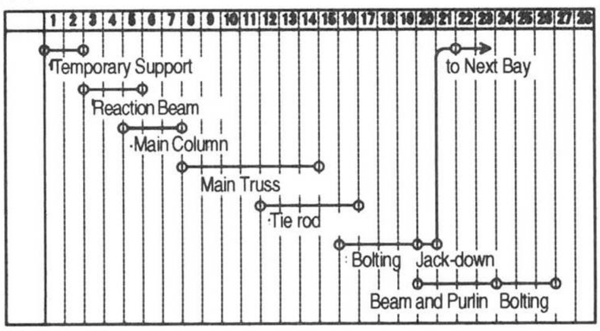


*Figure 9: Construction schedule of main roof (for 1bay)*

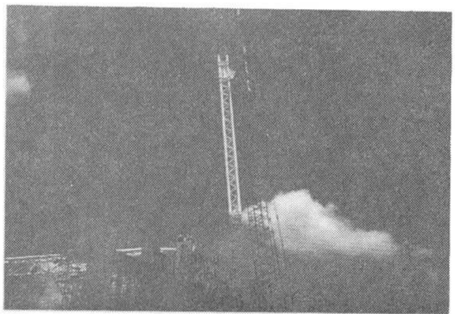

*Photo 3: Installation of main column*

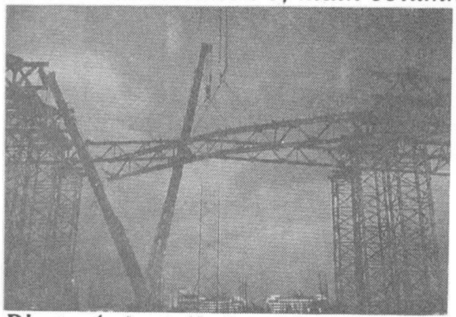

*Photo 4: Installation of main truss*

*Photo 5: Assembly of tie rod*

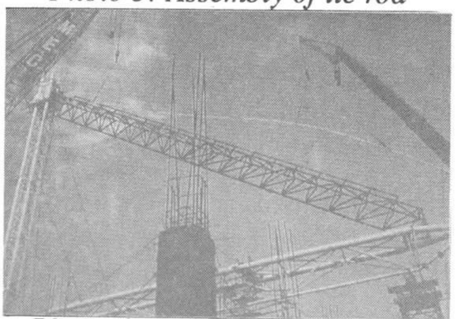

*Photo 6: Installation of tie rod*

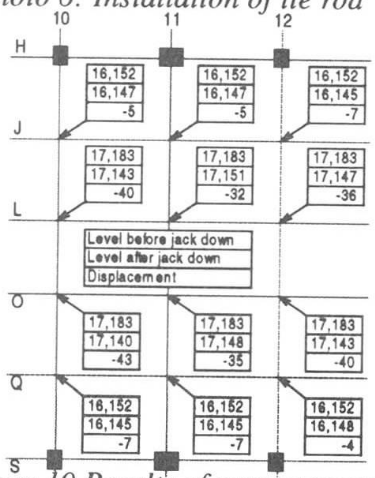


*Figure 10 Results of measurement of bay 3*

## 4.2 Construction procedure

The main steel frames of roof were fabricated in Thailand except the tie rods. The fabricator of steel structure has qualification of Class A of Steel Frame Construction Association in Japan and qualification of other main organizations such as API and ASME. The tie rods were made and finished in Japan. After testing and packing they were sent to the construction site.

Figure 7 shows the construction procedure of the roof frames. The roof frame is in unstable state until one bay is assembled. So as to ensure the stability, we adopted the Jack-down process. Namely, the temporary support is used during construction, and after completion of assembling the support is removed. The jack-down was repeated 7 times to complete the construction. To jack down, the filler plate laid on the top of tentative frame, being supported with the hydraulic jack, is withdrawn. The filler plates were drawn out one after another successively, and the jack was lowered. After the whole structure was suspended, jack-down was finished. Figure 8 shows the outline of jack-down process.

While there are several methods to construct suspension structures, we adopted the method based on length control. The deformation of structure was previously calculated, and the position of each member and length of tie rods were adjusted and controlled so that the members were arranged in the specified position after completion of jack-down. For this construction method, it is important to ensure the accuracy of construction. Especially, error of tie rod length decides the stability of the whole structure. Therefore severe check was given to the length control when the members were assembled on the ground. Additionally, we judged some imperfection of length of tie rod and position of steel members cannot be avoided during construction process. So we carried out calculation of roof frame assuming some patterns of imperfection, and checked safety of the whole frames. Table4

*Table 4 Patterns of imperfection analysis*

| Cases | deformation of main truss |
|---|---|
| Asymmetrical pattern |  |
| Symmetrical patterns (tie rods at center of span are longer) |  |
| Symmetrical patterns (tie rods at center of span are shorter) |  |

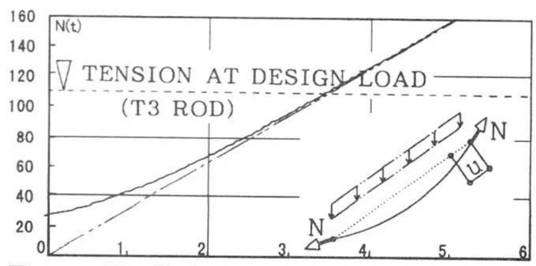


*Figure 11: Relationship between elongation and tension*

shows examples of assumed pattern of the imperfection. In all cases, we assumed deferences in length of tie rod were 1/1500 of total length of tie rod.
Figure 9 shows the steel frame construction schedule for each bay. It took about 25 days to construct one bay. If the lap period is taken into account, about 120 days are required to construct the whole roof. Photo 3,4 show the installation states.

### 4.3 Installation of tie rods

Before the tie rod was installed, the temporary support beam was installed between the column top and the front end of reaction beam. The total length of the longest tie rod T3 exceeds 39 m. It was too long to carry to the construction site, so it was divided into some parts and then jointed at the construction site. Therefore, the end of tie rod was threaded, and each end of the tie rod could be jointed with the aid of coupler. Photo 5 shows the assembling state.
After on-ground assembling the length of each tie rod was inspected, because the length cannot be adjusted after construction. To measure the length, the steel tape was used. Measurement error was within 2 mm. After length inspection the members were lifted with two cranes, and the pin was inserted into the end hole of tie rod at its both ends. Photo 6 shows the installation state.

### 4.4 Installation accuracy of frames

After completion of jack-down, the level of main trusses and inclination of column top were measured. Figure 10 shows the results of measurement of bay 3. Deformation of main truss is almost symmetrical at left and right sides, so that the accuracy control based on length control is proved to be satisfactory. The calculated displacements, based on linear analysis of center part and outer side were 80 mm and 40 mm, respectively, but the actual displacements were 43 mm and 7 mm. The reason why the displacements was so small is that sag of tie rod which was not taken into account in linear-calculation was greater than expected value. In the gravity, the relation between tension and the distance of each end is nonlinear and gravitational tension arises because of the deflection by self weight (Figure 11 ). At the level of design load, the self weight ratio is 50% in total load and non-linear effect is negligible. However, in the construction stage, the load is only self weight of the roof structure so the tension and the nonlinear effect are to be taken into consideration.

## 5. Conclusion

In this paper, we have discusses the design and construction of BITEC which has large roof of suspension structure. During structural design and construction, we obtained following important points.
1) Using tie rod as the suspension member makes the structural design clear and makes the accuracy constrol easy by coupler joint in the construction process.
2) The structural design employing "Self-balancing system" cam make the suspension structure stable in the election process.
3) It is indispensable to carry out the structural analysis considering imperfection and geometrical non-linear effect of the structural members - especially tie rods - for the accurate construction.

## Acknowledgment

We wish to express our appreciation to Dr. Prasarn of Parinthon Co. who is an active and energetic project owner, to staffs of Design 013 Co., ACS Co. and Management 103 Co. who supported designing and management, as well as to other all persons who took parts in this construction work.

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