ADVANCED SUSPENSION BRIDGE TECHNOLOGY
AND
THE FEASIBILITY OF THE SUNDA STRAIT BRIDGE

By :

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SYNOPSIS

The development of long span suspension bridges world wide is first reviewed to identify what the limit of span lengths would be for crossing the Sunda Strait. Its scientific background shows that this development can be divided into three successive generations, the third of which being the latest and most advanced one, capable of achieving ultra-long spans. Therefore, the technology of the third generation should undoubtedly be applied for crossing the deep and wide sea valleys of the Sunda Strait. Based on unit costs derived from recent suspension bridge projects, the construction cost of the Sunda Strait Bridge is then assessed and based on the anticipated traffic volume crossing the strait and its growth in the future, the financial viability of the project is finally shown.

1. INTRODUCTION

This paper is based on a report prepared by the author for BPP Teknologi as the executing agency of the Sunda Strait Bridge Project, presented on 1 May 1997. Resulting from this report, the tunnel solution for crossing the Sunda Strait has definitely been discarded, because of the much higher cost it would require and other disadvantages it would pose as compared to the bridge solution. It has now become the policy of BPP Teknologi that all efforts should solely be concentrated on achieving the most optimal bridge solution for this crossing. In this connection it has also been decided, that the feasibility study up to the basic design stage of the bridge will be handled under the coordination and direction of BPP Teknologi. Only after the basic design of the most optimal bridge solution has been decided, the project will be offered to interested developers and investors either under a BOT, BOO or BOOT arrangement.

2. THE DEVELOPMENT OF SUSPENSION BRIDGE TECHNOLOGY

2.1. MAXIMUM SPAN

In considering the bridge solution for crossing the Sunda Strait, the first question that comes along is how long the maximum span of a suspension bridge can possibly be used for this crossing. If we look at the history of suspension bridges, the increase of spanlengths has always been related to the evolution of suspension bridge technology. Longer spans have first been achieved by substituting iron chain cables by drawn steel wires. The current standard galvanized steel strands used for the main cables of suspension bridges have a strength of 1,770 MPa and unit weight of 0.076 MN/m^3. But towards the end of the twentieth century the rapid increase of spanlengths is mainly the result of the better understanding of the various factors affecting the bridge performance. Let us now look at the spanlength of suspension bridges since the first "modern" suspension bridge at Menai (U.K.) with a span of 177 meters was constructed in 1826 up to the present day as listed in Table 1.

Table 1. Suspension bridges with significant jump in spanlength

Year	Name of Bridge	Country	Spanlength (m)
1826	Menai	U.K.	177
1883	Brooklyn	U.S.A.	486
1937	Golden Gate	U.S.A.	1,280
1994 *)	Messina Strait	Italy	3,300
2016 *)	Gibraltar Strait	Spain/Morocco	5,000

*) design completed

If the data in Table 1 are plotted with the x-axis showing the years and the y-axis indicating the spanlengths in meters (see Fig.1), the points are found to be located approximately on the following exponential curve :

$$y = 180\ e^{0.0175\,x}$$

This seems to be the curve indicating the maximum possible spanlength of suspension bridges that can be achieved by utilizing all of the technological knowledge and material strength available at a particular time in the history of suspension bridges.

The exponential nature of the above curve indicates, that the development of suspension bridge technology represented by the increase of spanlengths had been

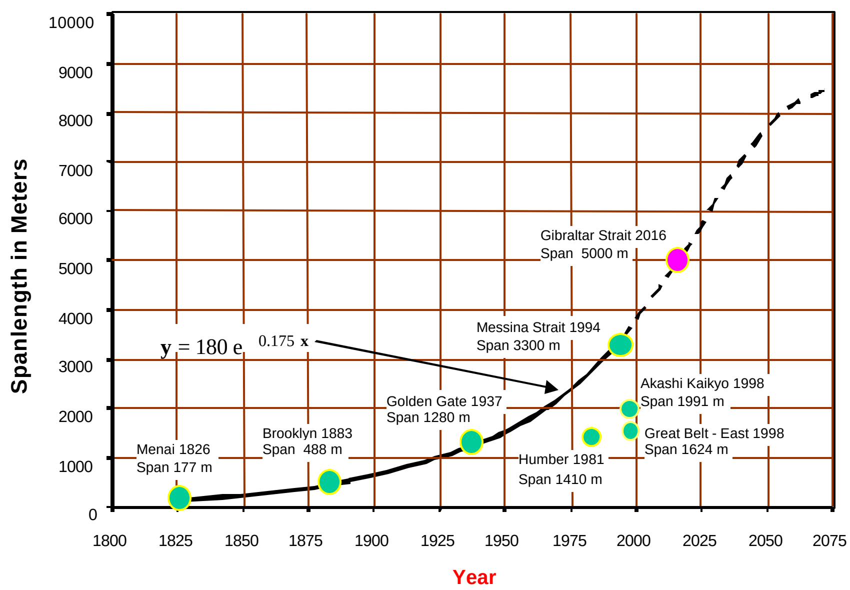

Figure 1. Development of spanlength of suspension bridges world wide.

relatively slow in the past, but has changed its pace rapidly towards the end of the twentieth century and further into the twenty first century. Since the technological knowledge on suspension bridges will have reached quite a high level by the next turn of the century, the continued increase of spanlengths in the early twenty first century will most probably be the result of the application of new cable materials, which are stronger and lighter than steel. A promising material in this case is Carbon Fiber Composite Cables (CFCC), fabricated in the form of seven-wire strands similar to the conventional prestressing strands. The strength of this material is 2,070 MPa with a unit weight of 0.015 MN/m^3, only 20% that of steel. It is apparent that a cable material with an 80% reduction in unit weight would have enormous impact on the design and construction of suspension bridges. Other desirable properties of CFCC are the highly corrosion resistant to acids and alkaline environments, good damping behaviour, high fatigue resistance and very little relaxation under sustained load. Based on this curve in the twenty first century we can foresee that the maximum possible span for a suspension bridge to cross the Sunda Strait, would be between 3,000 meters and 3,500 meters.

Now let us plot into the graph shown in Fig.1 suspension bridges with spanlengths of more than 1,000 meters as shown in Table 2. It can be seen, that all of the points fall below the curve. This fact can be interpreted as follows :

- the designers did not take full advantage of the existing suspension bridge technology and material strength available at that time to reach the maximum possible span, or
- it was not necessary to apply such a maximum span, as using a shorter span a more advantageous solution could be obtained.

Table 2. Long-span suspension bridges world wide

Year	Name of Bridge	Country	Spanlength (m)
1964	Forth Road	U.K.	1,006
1966	Ponte 25 de Abril	Portugal	1,013
1999	Kurushima-2	Japan	1,020
1999	Kurushima-3	Japan	1,030
1931	George Washington	U.S.A.	1,067
1973	Bosporus I	Turkey	1,074
1988	Bosporus II	Turkey	1,090
1988	Minami Bisan-Seto	Japan	1,100
1957	MacKinac	U.S.A.	1,158
1997	Hoga Kusten	Sweden	1,210
1937	Golden Gate	U.S.A.	1,280
1964	Verrazano Narrows	U.S.A.	1,298
1997	Tsing Ma	China (Hongkong)	1,377
1998	Jiangsu	China	1,385
1981	Humber	U.K.	1,410
1998	Great Belt-East	Denmark	1,624
1998	Akashi Kaikyo	Japan	1,991
2001 ?	Bali Strait	Indonesia	2,100
2010 ?	Sunda Strait	Indonesia	>3,000
?	Messina Strait	Italy	3,300
?	Gibraltar Strait	Spain/Morocco	5,000

2.2. SCIENTIFIC BACKGROUND OF SPANLENGTH DEVELOPMENT

In the history of suspension bridges the development of their spanlength as reflected by the increased technological knowledge of their designers, can be divided into three successive generations as follows :

First Generation

This is the generation of the classical and conventional suspension bridges. Having only a few hundred meters to span in their early development, loads on the bridge have been considered to be dominantly governed by gravity loads, because wind loads on the bridge are not significant.

The cable geometric stiffness of this First Generation of suspension bridges is not very large, so that stiff and heavy decks are required, leading to the classic concept of the stiffening truss girder as clearly represented by the Golden Gate Bridge (1937) with a spanlength of 1,280 meters and a stiffening truss girder depth of 7.6 meters and the Verrazano Narrows Bridge (1964) with a spanlength of 1,298 meters and a stiffening truss girder depth of 7.3 meters.

As for the seismic behaviour of this First Generation, the relatively stiff pylons and stiffening truss girder will all experience strong response vibrations due to earthquake ground shaking.

Further efforts to increase the spanlengths have met difficulties, since dead load becomes larger and the deck contribution in the total stiffness becomes smaller. The increase in dead load calles for heavier and deeper stiffening truss girders, resulting in increased wind drag forces, which can no longer be accommodated by the flexural stiffness of the deck, but have to be resisted by the geometric stiffness of the hangers, which are further transmitted to the main cables and further to the pylon tops. All of these factors require larger dimensions of the hangers, main cables and pylons.

The increased wind effects are also manifested by increased buffeting, vortex shedding and flutter phenomena. The deck configuration with the stiffening truss girder cannot produce a high overall torsional stiffness, resulting in a relatively high flutter sensitivity associated with low critical wind speeds.

Due to the above constraints, suspension bridges of this First Generation cannot have spanlengths in excess of about 2,000 meters. This limit is represented by the Akashi Kaikyo Bridge (1998) with a spanlength of 1,991 meters and a stiffening truss girder of 14 meters deep (see Fig.2a).

Second Generation

To achieve longer spans and simultaneously to be more economical in material use, it becomes apparent that suspension bridge design should go in the following direction :

- dead load must be kept to a minimum by introducing lighter deck configurations;

- wind effects in the form of drag, buffeting and vortex shedding must be kept to a minimum by introducing aerodynamic shapes to the deck cross-section and abandoning the deep and heavy stiffening truss girder;
- flutter sensitivity must be kept to a minimum by introducing a deck configuration, which together with the cable geometry provide a high overall torsional stiffness.

To give an answer to the above problems, a new concept of the Second Generation has been introduced, using a single closed-box deck system composed of stiffened steel panels. The self-weight of the deck is low and by giving the deck cross-section an aerodynamic shape, the system attains low drag forces, buffeting and vortex shedding. In addition the closed-box cross-section together with the cable configuration provide a good torsional stiffness, resulting in a low flutter sensitivity associated with high critical wind speeds.

As for the seismic behaviour of this Second Generation, the relatively flexible deck will experience only mild response vibrations due to earthquake ground shaking, while only the pylons which are still relatively stiff will experience strong response vibrations.

Two early examples of this generation are the Severn Bridge (1966) with a spanlength of 988 meters and deck depth of 3.05 meters and the Humber Bridge (1981) with a spanlength of 1,410 meters and deck depth of 3.82 meters.

To achieve longer spans, deeper box cross-sections of the deck are required to provide adequate stiffness, which are conflicting with the requirement to keep the self-weight and the wind effects low. These conflicting factors cause suspension bridges of this Second Generation to face difficulties to achieve spanlengths of more than 2,000 meters. The Great Belt-East Bridge (1998) with a spanlength of 1,624 meters and a deck depth of 4.35 meters represents a Second Generation suspension bridge, which has almost achieved the limit of possible maximum span (see Fig.2b).

Third Generation

In order to span distances of more than 2,000 meters, a more advanced version of the Second Generation has been developed, leading to the concept of the Third Generation. The self-weight is kept low by keeping the depth of the box shallow. To produce a high torsional stiffness several boxes are used adjacent to each other. Each of the boxes is given a good aerodynamic shape, so that drag, buffeting and vortex shedding can be kept low. The appropriate torsional stiffness produces further a very low flutter sensitivity associated with extremely high critical wind speeds.

Because of the extremely long spans of suspension bridges of the Third Generation, their pylons become also extremely tall to maintain the appropriate sag to span ratio of the main cables. Consequently the pylon becomes very flexible and the deck even more. Subjected to ground shaking, a suspension bridge of this generation will only experience strong response vibrations in its pylons. Their relatively high flexibility will act as a base isolator, preventing further propagation of seismic waves, so that the deck remains relatively calm.

The Messina Strait Bridge is the first example of a suspension bridge of the Third Generation designed by Stretto di Messina. Its central span is 3,300 meters and the cross-section of the deck shows a triple-box concept, each box having an extremely aerodynamic shape with a depth of only 3 meters. The middle box carries a double track railway, while each of the side boxes carries three lanes of carridge way and a side lane for pedestrians. These three boxes are connected by cross beams with a depth of no more than 4.5 meters placed at 30 meters intervals, with an open space between each box (see Fig.2c). These open spaces are covered with grids allowing the air to flow through reducing aerodynamic lift and moment. In addition those spaces with the grid topping are also utilized as service and emergency lanes. The design has been completed in 1994, but it is not known yet when construction will be started.

A second example of a suspension bridge of the Third Generation is the Bali Strait Bridge, designed by Brown Beech & Associates, which is a B.O.T. proposal submitted by Scotia Bali Bridge Co. Ltd. to the Department of Public Works. The bridge has a central span of 2,100 meters and at its final phase will carry a six-lane divided carridge way. Other ultra-long suspension bridges of the Third Generation now being designed are in Japan (Tokyo Bay) and Venezuella (Maracaibo).

The maximum span that can be achieved by a suspension bridge of the Third Generation is estimated to be around 5,000 meters, represented by the Gibraltar Strait Bridge with a spanlength of 5,000 meters. The basic design by T.Y. Lin International has been completed in 1992, but it is not known yet when the design process will be resumed.

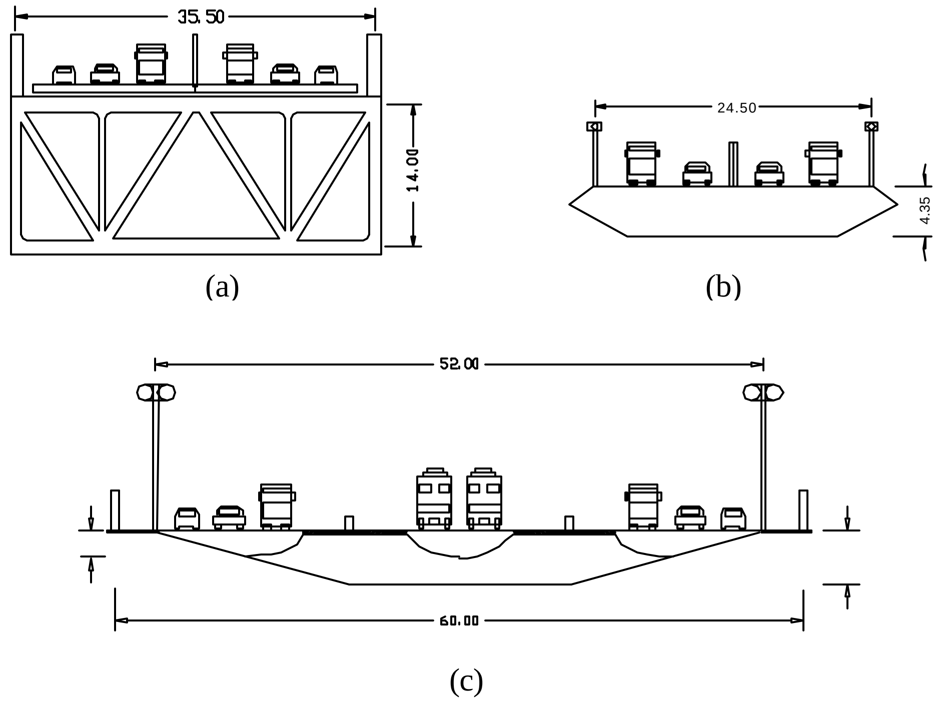

Figure 2. Deck cross-section of suspension bridges, (a) of the Akashi Kaikyo Bridge, (b) of the Great Belt-East Bridge and (c) of the Messina Strait Bridge.

Table 3 shows the different dynamic characteristics and flutter sensitivity of the three generation of suspension bridges. In this table the ratios of the first frequency of torsional and flexural modes are indicators of the bridge's sensitivity to flutter. This ratio must always be larger than 1. If the ratio is excatly 1 the flexural and torsional modes become identical, leading to a condition of flutter instability. This is what had occurred to the First Tacoma Narrows Bridge with a spanlength of 854 meters, which had collapsed on 7 November 1940, only four months after it was opened, due to a moderate wind speed of only 70 km/hour (19 m/sec). From Table 3 it can be seen that the Messina Strait Bridge attains an extremely high critical wind speed of 90 m/sec. Since a wind speed of 60 m/sec (wind Level 3) has a mean return period of 2,000 years, it can be said that the critical wind speed will never happen; in other words the Messina Strait Bridge is flutter free.

From the above discussion it is apparent, that to cross the wide and deep sea valleys of the Sunda Strait, needless to say that the concept of the Third Generation suspension bridge should be adopted.

Table 3. Vibration characteristics and critical wind speed of suspension bridges.

Name of Bridge	Spanlength (m)	Type of Deck	1st Freq. Flexural Mode (Hz)	1st Freq. Torsional Mode (Hz)	Ratio 1st Freq.Flex and Tors. Modes	Critical Wind Speed (m/sec)
First Generation						
Innoshima (Japan)	770	truss	0.178	0.374	2.10	66
Minami-Bisan Seto (Japan)	1,100	truss	0.126	0.324	2.57	80
Akashi Kaikyo (Japan)	1,991	truss	0.064	0.142	2.22	78
Second Generation						
Severn (U.K.)	988	single box	0.143	0.374	2.62	65
Humber (U.K.)	1,410	single box	0.100	0.280	2.80	60
Great Belt-East (Denmark)	1,624	single box	0.099	0.272	2.75	70
Third Generation						
Bali Strait (Indonesia)	2,100	multi box				
Sunda Strait (Indonesia)	>3,000	multi box				
Messina Strait (Italy)	3,300	multi box	0.060	0.080	1.33	90
Gibraltar Strait (Spain/ Morocco)	5,000	multi box				

2.3. DEVELOPMENT IN INDONESIA

Existing suspension bridges in Indonesia and the ones now still under construction, have spans only in the hundreds of meters, not yet exceeding 1,000 meters. As shown in Table 4 the first three suspension bridges, namely the Membramo, Barito and Mahakam II Suspension Bridges are still of the First Generation, using the stiffening truss girder concept. Firstly this is because the spanlengths are just a few hundred of meters and secondly because their construction is relatively simple for their remote locations.

Table 4. Long-span Bridges in Indonesia

Year	Name of Bridge	Spanlength (m)	Generation
1996	Membramo	235	First
1997	Barito	240	First
1998	Mahakam II	270	First
1998	Batam-Tonton	350	Second (cable-stayed)
2001 ?	Bali Strait	2,100	Third
2010 ?	Sunda Strait	>3,000	Third

The bridge between Batam Island and Tonton Island, one of the six Barelang bridges, is in fact not a suspension bridge, but a cable-stayed bridge. With its deck cross-section in the form of an aerodynamic single closed-box, its concept is equivalent to a Second Generation suspension bridge concept.

As mentioned before, the Bali Strait Bridge with a spanlength of 2,100 meters is a suspension bridge of the Third Generation, which is still a B.O.T. proposal. The Sunda Strait Bridge, which is the subject of this paper, will require spanlengths in excess of 3,000 meters to cross the existing wide and deep sea valleys.

3. COST ESTIMATE FOR THE SUNDA STRAIT BRIDGE

3.1. UNIT COSTS

For the purpose of estimating the construction cost of the Sunda Strait Bridge unit costs have been derived from total costs of recent ultra-long suspension bridge projects around the world as listed in Table 5.

Table 5. Unit Costs of Long-Span Suspension Bridges

Name of Bridge	Cost in million USD/Km (1997)
Messina Strait Suspension Bridge (Italy), spanlength 3,300 m :	
Long-span suspension bridge for 6-lane divided roadway, double track railway, 2 lanes for emergency and service vehicles, 2 side lanes for pedestrians	490
Long viaduct for road and railway for the approaches	130
Road and railway, including cut and fill and tunnel on ground	100
Tsing Ma Suspension Bridge (China), spanlength 1,377 m :	
Long-span suspension bridge for 6-lane divided roadway, double track railway, 2 lanes for emergency and service vehicles	450
Akashi Kaikyo Suspension Bridge (Japan), spanlength 1,991 m :	
Long-span suspension bridge for 6-lane divided roadway, 2 lanes for emergency and service vehicles	490
Great Belt-East Suspension Bridge (Denmark), spanlength 1,624 m ;	
Long-span suspension bridge for 4-lane divided roadway, 2 lanes for emergency and service vehicles	230

It is interesting to note that although the cost per kilometer of the Messina Strait Bridge and the Akashi Kaikyo Bridge is the same, with the Third Generation technology applied in the

Messina Strait Bridge a much longer span with an additional double railway track can be achieved. This confirms the cost effectiveness of the Third Generation technology .

3.2. BRIDGE ALIGNMENT

The bridge alignment must be determined in such a way that the most optimal suspension bridge spans and foundation depths are achieved, which can be built at the lowest possible cost. This study is part of the feasibility study that is still to be conducted.

Several investigators had attempted to examine several bridge alignments along with the bridge spans to cross the Sunda Strait. In 1992 the author had investigated three alternatives of bridge spans, from which it was found that a combination of 2 suspension bridges (of the Third Generation) with a central span of 3,500 meters provided the lowest cost. Its alignment and the crossing structures can further be described as follows (see Fig.3).

- Pulau Jawa - Pulau Ular : 3 kilometer viaduct
- Pulau Ular - Pulau Sangiang : 7.8 kilometers suspension bridge
- Pulau Sangiang : 5 kilometers road and railway
- Pulau Sangiang - Pulau Panjurit : 7.6 kilometers suspension bridge
- Pulau Panjurit : 1 kilometer road and railway
- Pulau Panjurit - Pulau Sumatera : 3 kilometers viaduct

Other investigators like the JICA team (1992) assigned by the Department of Public Works and Pakarti Trimitra Group (1996) in a B.O.T proposal, have proposed other alignment alternatives along with different bridge spans. Since the most optimal alignment and associated bridge spans are still to be investigated in the coming feasibility study, for the sake of simplicity, in the further discussion in this paper the alignment proposed by the author will be used.

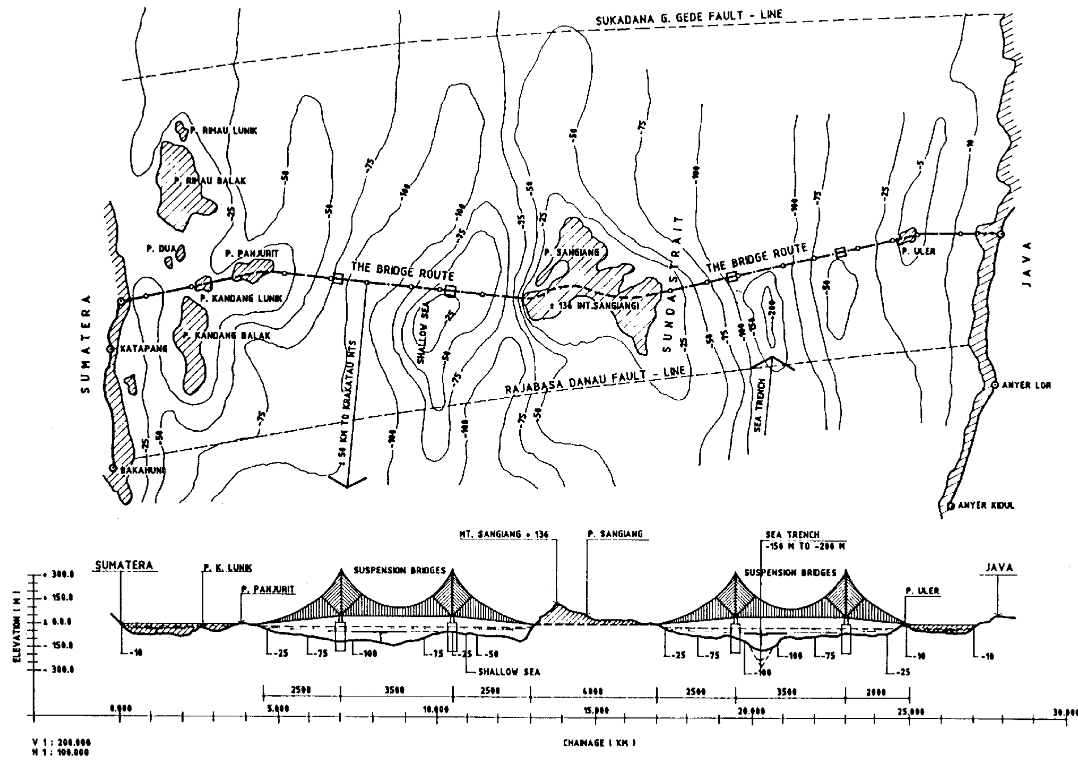

Figure 3. The Sunda Strait Bridge alignment passing through P. Ular, P. Sangiang and P. Panjurit.

3.3. CONSTRUCTION COST

Using the unit costs of the Messina Strait Suspension Bridge and the bridge alignment proposed by the author, the construction cost of the Sunda Strait Bridge may be computed as follows :

-	P. Jawa - P. Ular	: 3 km x USD 130 mill./km	=	USD 390 mill.
-	P. Ular - P. Sangiang	: 7.8 km x USD 490 mill./km	=	USD 3,822 mill.
-	P. Sangiang	: 5 km x USD 100 mill./km	=	USD 500 mill.
-	P. Sangiang-P.Panjurit	: 7.6 km x USD 490 mill./km	=	USD 3,724 mill.
-	P. Panjurit	: 1 km x USD 100 mill./km	=	USD 100 mill.
-	P.Panjurit-P.Sumatera	: 3 km x USD 130 mill./km	=	USD 390 mill.
		Total Cost	=	USD 8,926 mill.

The above construction cost estimate for the Sunda Strait Bridge may still be reduced, because of the following reasons :

- the cost calculation has not yet taken into account the optimal condition of the bridge span and the foundation depth, so that further reduction is possible;
- the unit costs have been derived from the construction cost in Italy, based on material and labour costs prevailing in Italy, so that further reduction is possible if local prices for the material and local labour cost are considered.

Taking the likely reduction to be about 20%, a more realistic estimate of the construction cost of the Sunda Strait Bridge would be around USD 7 billion or approximately Rp.16,8 trillion.

4. FINANCIAL AND ECONOMIC ANALYSIS

4.1. FINANCIAL ANALYSIS

Costs and Project Schedule

- Cost for additional investigations, feasibility study, basic design, including wind tunnel tests, environmental impact analysis, design quality assurance and cost-benefit analysis; tender documents for BOT/BOO/BOT, cost for the international panel of experts, cost for construction management	: USD 200 million :
- Detail design, construction drawings and physical construction cost of the bridge (BOT/BOO/BOOT)	: USD 7,000 million
Cost of the Project	: USD 7,200 million

The project schedule is as follows:

- Additional investigations and feasibility study, including cost-benefit analysis	: 2.5 years
- Basic design, including wind tunnel tests, environmental impact analysis, design quality assurance, verification of the cost-benefit analysis tender documents for BOT/BOO/BOOT	: 2.5 years
- Detail design, construction drawings and physical construct-	

ion (fast track) on the basis of BOT/BOO/BOOT : 8 years

Total : 13 years

Regarding the railway track it is assumed that the construction will start after the highway bridge generates revenues, i.e. after 3 years of operation and it will take an extra 2 years to complete. Thus the revenue from the highway operation will start to be collected after the 14th year, while that from the railway operation after the 19th year.

Funding and Expenditures

In this scenario, at the time the project is started an initial capital (self-derived capital) of USD 1 billion is available, which will be utilized for long-term loan interest payments and part of the pay back instalments while the bridge is not yet generating revenue.

The main investment cost of USD 7.2 billion is obtained from a long-term loan at 6% interest per annum with a grace period for the loan for the study and basic design of 5 years and for the detail design and physical construction of 8 years, when no revenue has been generated yet. The long-term loan must be paid off (instalments + interest) in a time frame not more than 25 years from the start of the bridge operation, or not exceeding 38 years from the start of the project.

The main investment cost of USD 7.2 billion, according to the project schedule, is disbursed according to the investment schedule as follows :

Year	1	2	3	4	5	6	7	8	9
% of payment	0.55	0.55	0.55	0.55	0.55	6.5	6.5	14	14

Year	10	11	12	13	14	15	16	17	18
% of payment	14	14	6.25	6	0	0	6	8	6

Starting from the 14th year, an Operation and Maintenance cost should be expended, which is calculated as 1% of the main investment per year with an escalation rate of 3% per annum.

After reaching the break even point, when the net income from operating the bridge with due consideration of its depreciation, reaches zero (and becomes positive afterwards), there will be the requirement of paying tax on income (PPh) amounting to 30% of net profit. The amount of depreciation is calculated as 0,5% of the main investment per year (flat) throughout the design life time of 200 years, which begins as soon as the bridge starts to operate in the 14th year.

As the initial capital (USD 1 billion) is only sufficient to pay off the long-term loan interest until a certain year, the further payment of this interest is provided from a short-term loan, not to exceed USD 3 billion at an interest rate of 8% per year for a period of no more than 20 years with a grace period of 10 years.

Income/Revenue

Income/revenue is collected from toll charges on motor vehicles/trains that use the bridge. In this case, the traffic volume during the first year of operation (the 14th year) or in the year 2011, is expected to be 12,900 vehicles per day. This estimate is obtained from the results of a study conducted by Pacific Consultants International (PCI) for the Department of Public Works titled "Study on the Expected Volume of Traffic at the Merak-Bakauhuni Crossing".

The increase in traffic volume is calculated as 10% per year until the maximum capacity of the bridge is reached, amounting to 162,300 vehicles per day, with a composition as follows: 37.2% large trucks/buses, 18.6% light trucks/buses, 44.2% passenger cars.

The toll fare is considered to be 2 times the present ferry fare, and as the ferry fare now for the Merak-Bakauhuni crossing is USD 30 for trucks and buses and USD 15 for passenger cars, the toll fare being considered is as follows: USD 60 for large trucks/buses, USD 60 light trucks/buses, USD 30 for passenger cars, with an escalation rate of 3% per year.

Income from railway traffic, which will start to be collected at the 19th year, is calculated conservatively as equivalent to the income from one traffic lane per track.

It should be noted here, that revenues from bridge leases for installation of various utility lines, such as the Extra High Voltage transmission link in the Jawa-Sumatera inter-connection system, fiber optics networks, natural gas pipe connection, etc. are not yet considered here.

Results of the Financial Analysis for the Sunda Strait Bridge Project

With the Cost Estimate and Project Schedule, Expenditures and Revenue of the Sunda Strait Bridge Project as outlined above used as input data for the computer program developed by PT. Wiratman & Associates for the feasibility analysis of investment projects, the following results have been obtained :

1. The Financial Internal Rate of Return (FIRR) reaches a value of 11.71% per year > 6% (o.k.).
2. The break even point is reached at the 20th year from the start of bridge operation or at the 33rd year from the start of the project (o.k.).
3. A short-term loan at an interest rate of 8% per year is required at the 11th year from the start of the project and will reach a maximum cumulative amount of USD 2.7 billion < USD 3 billion (o.k.) at the 22nd year and can be paid off (instalments + interest) within a period of 19 years < 20 years (o.k.), i.e. at the 17th year from the start of bridge operation or at the 30th year from the start of the project.
4. The long-term loan of USD 7.2 billion at an interest rate of 6% per year can be paid off (instalments + interest) exactly on time, namely at the 25th year after the bridge is in operation or at the 38th year from the start of the project (o.k.).

In Fig. 4 the present values for Expenditures, Revenue and Balance resulting from the Financial Analysis are shown, which clearly show that the break even point is reached at the 33rd year after the start of the project.

From the above Financial Analysis results, it is evident that based on the selected scenario, the Sunda Strait Bridge Project from a corporate point of view, has a high level of feasibility.

Sensitivity Analysis

To know what the influence of variation in revenue would be on the financial viability of this investment project, a Sensitivity Analysis has been performed. The following conditions affecting revenue have been considered :

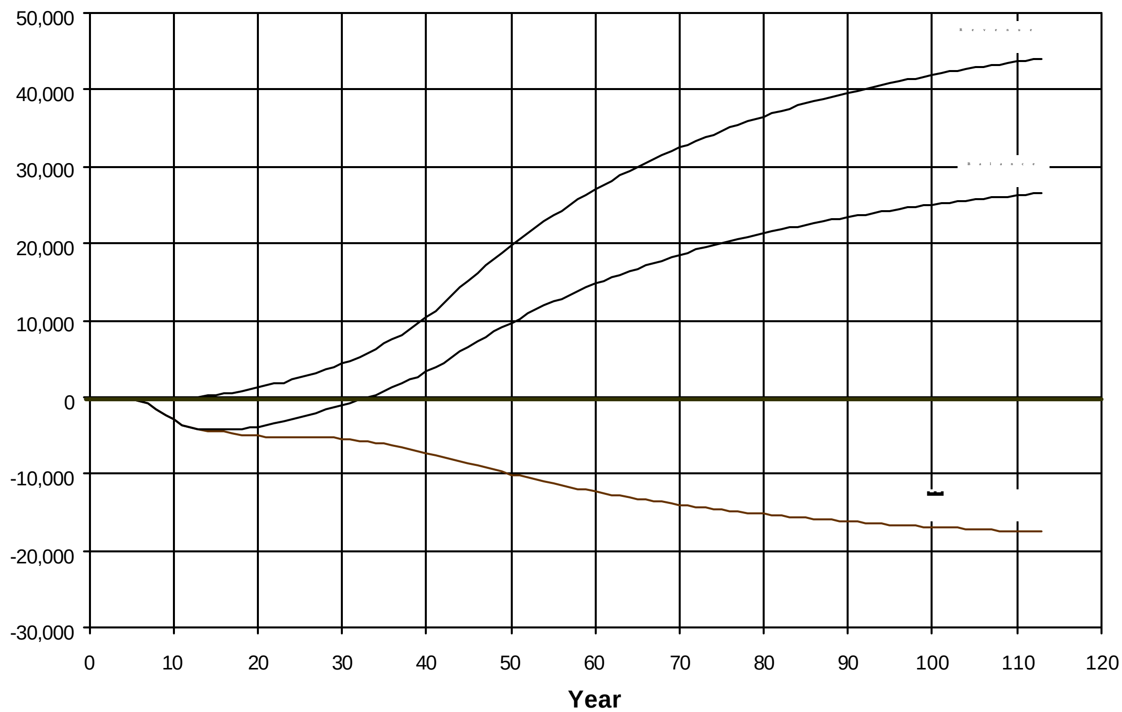

Figure 4. Graph showing present value for Expenditures, Revenue and Balance for the Sunda Strait Bridge Project.

Table 6. Results of Sensitivity Analyses

Traffic Volume (%)	Ratio of Toll Fare/Ferry Fare	FIRR (%)	Break Even Point after bridge operation (year)
100	1.5	10.64	24
	2.0	11.71	20
	2.5	12.60	18
90	1.5	10.42	25
	2.0	11.44	22
	2.5	12.30	19
80	1.5	10.18	26
	2.0	11.15	23
	2.5	11.97	21

- Traffic volume 100%, toll fare 1.5, 2 and 2.5 times of the existing ferry fare, 3% escalation rate per year.

- Traffic volume 90%, toll fare 1.5, 2 and 2.5 times of the existing ferry fare, 3% escalation rate per year.
- Traffic volume 80%, toll fare 1.5, 2 and 2.5 times of the existing ferry fare, 3% escalation rate per year.

The results of the analyses are listed in Table 6.

From Table 6 it is evident, that the Financial Internal Rate of Return (FIRR) will not be too much affected by variations in revenue due to variations in traffic volume as well as toll fares.

5. CONCLUSION

From the above discussions the following can be concluded :

1. The evolution of suspension bridge technology, reflected by the increasing spanlengths, is manifested in three successive generations, the third of which involving the latest advanced technology, capable of achieving ultra-long spans. The Third Generation suspension bridges, applying a multi-box deck concept, are characterized by their cost effectiveness due to their light self-weight, extremely low flutter sensitivity associated with very high critical wind speeds and good seismic performance. It is therefore important that this Third Generation suspension bridge technology be adopted for crossing the wide and deep sea valleys of the Sunda Strait.

2. The construction of the Sunda Strait Bridge is expected to cost some USD 7 billion (Rp.16.8 trillion) and requires some 13 years to complete. With the anticipated traffic volume crossing the strait and its development in the future, a toll fee of 1.5 to 2.5 times the present ferry fare is sufficient to reach a Financial Internal Rate of Return (FIRR) of more than 10% exceeding the bank interest rate for long-term loans, which confirms the financial feasibility of the project.

3. The economic benefit of constructing the Sunda Strait Bridge will be felt nation wide as a result of better crossing facilities between Jawa and Sumatera, facilitating rapid regional development on both sides of the strait, particularly in the tourism, industrial and natural

resources development sectors. During construction local economic boom will emerge, as the various activities supporting the bridge construction will mobilize a huge amount of fund and forces benefitting the welfare of the region.

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