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Study of Failure Factors Suspension Bridge: The Case of 470 Meter Suspension Bridge Collapse

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Abstract

Suspension bridge is a type of bridge that has the ability to overcome very long span. Many countries in the world have built suspension bridges to connect two areas separated by deep water body. Also Indonesia actually ever had its suspension bridge with moderate span length that helped connecting the transportation network of the maritime country. Unfortunately, humans would not be that perfect to succeed in their first trial including building very complex structure like suspension bridge. It is recorded that some suspension bridge failures happened across the earth and Indonesia was hapless to experience it too. Suspension bridge is a complex structure that consists of distinct parts carrying loads together. This strongly needs careful calculations and advanced design technologies along with proper construction and intensive maintenance to assure the performance of the structure. Many things have been learn from the collapse of a suspension bridge a couple years ago in Indonesia. From the design aspect, the connecting element had an abrupt change in geometry causing stress concentration effect. Adding it with anchorage movement, clamp connection slip, material's strength degradation and poor maintenance had caused a disastrous tragedy. The bridge collapsed upon the readjustment of deck position by mean of jacking at the lower connection of hanger. Finally, this paper attempted to assess these factors in the purpose of making a reference for future development in this country.

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Keywords: suspension bridge, collapse, connection, stress concentration, anchorage movement, clamp connection slip, jacking

1. Introduction

There area various methods developing various types of bridges that serves to connect the two places in accordance with the distance of obstacles. Ranging from simple wooden bridge, concrete bridge, steel truss bridge until the bridge with steel cable strut. Bridge type which is supported by a cable bridge type that can accommodate the longest stretch.

On the bridge with steel cables, loads crossing the bridge deck along with other loads including the weight of its own deck supported by cables to a buffer and then transferred to the bridge pylons and anchor blocks. One type of bridge with support cables is a suspension bridge or suspension bridge (suspension bridge). Bridge with the longest span in the world today is the Akashi-Kaikyo bridge in Japan with a main span along 1,991 km. This bridge is a bridge-type suspension.

In Indonesia there are not many bridges with the type of cable support built. Moreover, the type of suspension bridge that is rarely encountered in this country. This is because for most of the purposes of the bridge in Indonesia is still limited to the overpass and the river is not too wide so it does not require a long stretch. But there are also some wide rivers, straits and overpasses connecting the bridge with support cables. Therefore, the ability to be the planning and construction process of the

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bridge such as this needs to be developed because there are many areas that are separated by wide rivers and straits between islands that need to be connected later in life.

The suspension bridge with a length of 470 m across the second longest river in Indonesia collapsed on November 26, 2011, approximately at 16.15 pm. This bridge collapsed during maintenance process is being carried out. Maintenance is performed is the process of jacking the bridge deck and then be normalized to the deflection that occurred on the bridge. Maintenance is carried out without closing the flow of traffic. Vehicles still pass the full capacity of two lanes in both directions. Leverage is done in the middle of the span on both sides.

At the time this process occurs leverage bridge collapse. This collapse was preceded by breaking the connection between the main cable and the cable hanger in the middle of the span which further results in a redistribution of the burden to other parts of the bridge. Failure of one of these components appeared to have sparked a catastrophic failure of the structure so that the bridge deck can no longer be detained as a result of most of the top clamp connection has failed. Total collapse of the structure occurs in less than 20 seconds resulted in at least 24 deaths and 12 reported missing. This incident has given profound sadness to the people and give a reflection on how the condition of the construction industry in Indonesia.

Studies have been done to examine the causes of the failure of the bridge. The study shows many aspects of the failure of the bridge structure. In this final project will discuss the effect of shifting the armature block, slip on the connection clamps as well as leverage the deck of the bridge structure. Analysis emphasized the connection component which is the most critical component in the structure of the bridge. The purpose of this study was to determine the influence of minor failure of the bridge structure and the maintenance of the strength of the bridge structure and estimate the degradation of the quality of the material. When the influence of minor failure of the bridge structure and the maintenance of the strength of the bridge structure and estimate the degradation of the quality of the material is known, then the failure of long-span bridges can be reduced.

2. Literature Review

2.1 Bridge with Cable Support

There are various types of systems bridge, bridge with cable support known for its ability to accommodate a very long span. Currently, the bridge with support cables can have a stretch of 200 meters long by two kilometers or even more. Approximately ninety percent of stretch of the bridges are currently in the range.

Most bridges with cable support system has a structure with the following components:

- deck bridge (stiffening gireder / truss)
- cable system
- Pilon
- Armature & Block armature

The process of transferring the burden of vehicles passing over the bridge first of all be borne directly by the bridge deck or can also be stiffening girders. Accepted load transferred to the bridge deck bridge pylons via cable systems and then forwarded to the foundation. While the armature block withstand tensile force occurs on the cable and longitudinal force that occurs in the bridge. Armature system can be self-anchored or tethered to the massive concrete anchor blocks.

Bridge with support cables distinguished by a cable system configuration used. Suspension bridge cable system consists of a parabolic shaped main cables and vertical cable which can then be called hanger deck of the bridge that connects the main cable. Generally, the system structure of the suspension bridge has three spans consisting of a main span and two side spans. Three stretch of the

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bridge is in most cases a symmetrical shape with the same side span length. However, under certain conditions, long-span-side span can be different.

2.2 Suspension Bridge

The origin of the use of the suspension bridge has been recorded there since primitive times and became a precursor suspension bridge technology that has been growing rapidly at this time. The use of iron as a material in the suspension bridge began in Europe in the 16th century and began to develop in the 18th century. Although the use of wrought iron as the main cable bridge prevalent in the mid 18th century, the development of long-span bridges are still stagnant. Until the discovery of the steel in the 19th century before long span suspension bridge grow rapidly until now. Now the drawbridge most suitable to be applied to accommodate the needs of a very long stretch.

The main components include the suspension bridge structure constituent parts that have been mentioned previously, namely stiffening girder, cable systems, pylons, and the armature block. However, the significant difference with cancang bridge is a cable system that is used. Cancang bridge using a linear cable that transmits the load from the deck directly whereas a suspension bridge cable system consists of the main cable and the cable hanger.

Stiffening girder / stiffening truss is a structure that extends from one abutment to abutment them as a crutch loads passed over it. There are two alternatives for the suspension bridge deck stiffening girders or stiffening truss therefore the above-mentioned these two terms. Suspension bridges in the world adopt more as a deck truss system because it can provide bending stiffness and torque are sufficient and both the aerodynamic behavior. But does not close as the use of box girder deck system as applied to the Severn Bridge in England. In the process of designing this new concept on the bridge deck and hanger configuration drawbridge into use.

2.3 Cable

The main elements forming the main cable bridge is a wire made of steel with a tensile stress characteristics that are very large in comparison with ordinary structural steel. Great tensile strength obtained from the composition of the steel wire which has a higher carbon content than allowed on structural steel. However, the advantages of the tensile strength to be paid with lower ductility properties of the cable. In addition to the high carbon content makes it difficult to weld wire

Wire generally cylindrical shape with a diameter ranging from 3 to 7 millimeters. Typical wire on a suspension bridge using a diameter of about 5-5.5 mm. The following table shows a comparison between a steel wire with structural steel in general.

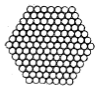
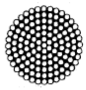
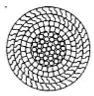
Table 1. Comparison of structural steel and steel wires

			Baja struktural	
	Satuan	Kabel baja konvensional	Mild	High strength
Tegangan leleh	MPa	1180	240	690
Tegangan tarik	MPa	1570	370	790
Regangan putus	%	4	24	
Modulus elastisitas	GPa	205	210	210
Komposisi kimia				
	C	0,80%	0,20%	0,15%
	Si	0,20%	0,30%	0,25%
	Mn	0,60%		0,80%
	Cu	0,05%	0,20%	0,30%
	Ni	0,05%		0,80%
	Cr	0,05%	0,30%	0,50%
	P	0,03%	0,04%	0,03%
	S	0,02%	0,04%	0,03%

2.4 Type Of Cable

To form the main cable bridge, steel wire must first be fabricated as a strand. Strand as the main cable consists of wire with a considerable amount and have some kind of cross-sectional configuration. Strand fairly simple often encountered as a prestressed concrete tendon in the form of a spiral consisting of seven wire with a wire diameter of 5 mm.

Table 2. type suspension bridge cable.

Name	Shape of section	Structure	Bridge
Parallel Wire Strand		Wires are hexagonally bundled in parallel.	Brooklyn Humber Great Belt East Akashi Kaikyo
Strand Rope		Six strands made of several wires are closed around a core strand.	St.Johns
Spiral Rope		Wires are stranded in several layers mainly in opposite lay directions.	Little Belt Tancarville Wakato
Locked Coil Rope		Deformed wires are used for the outside layers of Spiral Rope.	Kvalsund Emmerich Älbsborg New Köln Rodenkirchen

2.5 Deck

The deck is a suspension bridge structural elements that receive direct most of the loads that occur. Traffic loads on hold first by the deck as well as a large wind loads on the deck. Besides heavy bridge deck provide the largest proportion in the structure of the upper bridge.

The deck on the bridge with support cables have the advantage that the deck has a lot of wires supporting pedestal. The number pedestal on the deck of the bridge to make the moment happen to be reduced compared to the absence of a cable system. This is illustrated in Figure 1 wherein the weight ratio of the moment itself in both conditions look very much different.

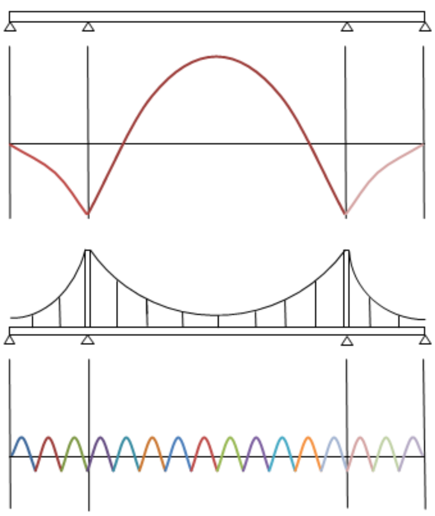


Fig. 1. Illustration of a comparison moments that occur on the cable without the support girder and deck on a suspension bridge.

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2.5.1 Deck Rigidity

Strength deck contribute to the load bearing traffic bridge, therefore it is important to note rigidity deck. In principle, the bridge deck must have sufficient rigidity to withstand bending loads both in the span between the hanger menanjang or transverse direction. In terms of stiffening trusses stiffness is provided by the component in the longitudinal stringers and cross girders in the transverse direction.

Then, the bridge deck should also be able to distribute concentrated loads that occur on the bridge to a hanger. Centralized uneven load distribution to hanger will reduce the design load on the hanger. Additionally enough stiffness produces a more uniform deflection on deck.

During her maid bridge will experience a force in a lateral direction as the wind and possible earthquake. Therefore deck must also have sufficient rigidity in the lateral direction in order to avoid excessive deflection Flaws or mainly due to the wind. Lateral stiffness is affected by the conditions on the deck and on the bridge perletakannya with lateral prisoners armature block system also carried by cable systems together with the deck.

Bridge deck also had a moment of torque due to the load of the vehicle does not always fill all the lanes of the road. Moment due to the load torque is not the draw it had to be held by the cable system when used two field hanger. However, the stiffness of the deck in the hold torque is also needed so that the moment of torque can be distributed to both the field of hanger evenly.

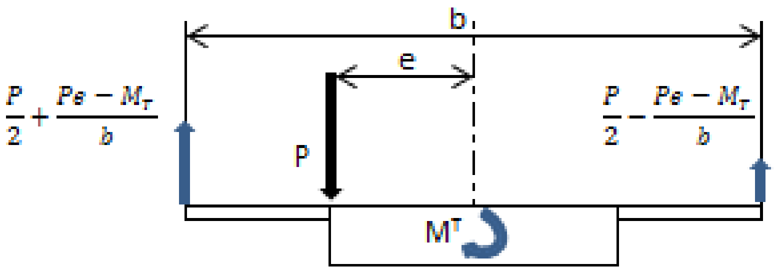

Fig. 2. Combination of prisoners due to an eccentric load on the bridge deck.

2.6 Pilon

Pilon is a vertical structure on the bridge which receives most of the axial force from the load bridge. Axial force on pylons transferred by the main cable suspension bridge while the horizontal force also occur as a result of the wind load either directly occur on pylons and transferred from the wires. Bridge pylons section design is a process that is not too complicated because the required parameters can be given. The thing to note is to make an effective cross-section pylons in the dominant weight-bearing axial load of the cable system. Such as in the design of steel pylons were widely used for suspension bridges, cross-sectional size be kept small by adding thick plate constituent. Thick plates are used measuring between 25 mm to 100 mm.

Because the compressive force that occurs in a very large dining pylons need to anticipate the occurrence of buckling failure by installing confessors on foot pylons. First, longitudinal stiffeners are also part sectional contribute withstand axial force on the pylons. Longitudinal stiffeners fitted at a distance of 30 to 40 times the thickness of the plate. Although the bridge pylons do not receive significant torque loads, the direction transverse stiffeners also installed to reinforce the longitudinal stiffeners as shown in Fig. 3.

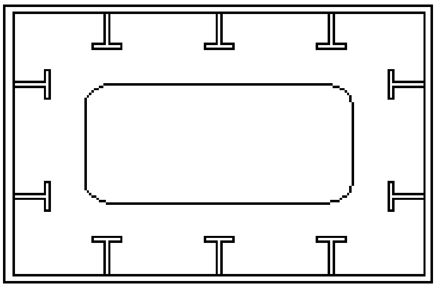

Fig. 3. Example of a cross section of steel pylons

2.7 Bridge load

Loading on the bridge model final bridge failure sensitivity analysis using standard loading bridge SNI T-02-2005.

Own weight is the weight of the materials and parts of the bridge that is a structural element. Weight is determined by multiplying the density of the material by volume. Here is a table of contents and weight of the mass density of materials commonly used in bridge structures.

2.7.1 Additional Dead Load (superimposed Dead Load)

Additional dead load includes all the non-structural elements contained on the bridge. It should be noted that the additional dead load may increase the amount at a later date as a result of the addition of the asphalt layer on the road surface. Traffic load applied to the load-lane bridge consists of a "D" and load the truck "T". Lane load "D" works on the whole width of the vehicle lane on the bridge and have an impact equivalent to convoy truth. Load truck "T" is the burden of a heavy vehicle with three axles are placed in several positions in the traffic lane plan. Each axle comprises two loading contact area which is intended as a simulation pengruh wheels of heavy vehicles. Only one truck load "T" that is applied to each lane of traffic. Generally load "D" will be decisive on the bridge with a medium to long span. While the truck load "T" determines the bridge with a short span.

2.7.2 Load Combination

Load combinations for bridges is divided into combinations of serviceability limit and combinations of ultimate limit. Loading combination of both can be seen in Table 3. In a load combination of ultimate combination of permanent action and action transient load multiplied by a predetermined factor.

Table 3. Combination of loading for serviceability and ultimate limit state.

Aksi	**Kelayanan**						**Ultimit**					
	1	2	3	4	5	6	1	2	3	4	5	6
Aksi Permanen : Berat sendiri Beban mati tambahan Susut rangak Pratekan Pengaruh beban tetap pelaksanaan Tekanan tanah Penurunan	X	X	X	X	X	X	X	X	X	X	X	X
Aksi Transien : Beban lajur "D" atau beban truk "T"	X	o	o	o	o		X	o	o	o	o	
Gaya rem atau gaya sentrifugal	X	o	o	o	o		X	o	o	o		
Beban pejalan kaki		X						X				
Gesekan perletakan	o	o	X	o	o	o	o	o	o	o		o
Pengaruh suhu	o	o	X	o	o	o	o	o	o	o		o
Aliran / hanyutan / batang kayu dan hidrostatik / apung	o		o	X	o	o	o		X	o		o
Beban angin			o	o	X	o	o		o	X		o
Aksi Khusus : Gempa											X	
Beban tumbukan												
Pengaruh getaran	X	X										
Beban pelaksanaan						X						X
" X " berarti beban yang selalu aktip " O " berarti beban yang boleh dikombinasi dengan beban aktif, tunggal atau seperti ditunjukkan.	(1) = aksi permanen "x" KBL + beban aktif "x" KBL + 1 beban "o" KBL (2) = aksi permanen "x" KBL + beban aktif "x" KBL + 1 beban "o" KBL + 0,7 beban "o" KBL (3) = aksi permanen "x" KBL + beban aktif "x" KBL + 1 beban "o" KBL + 0,5 beban "o" KBL + 0,5 beban "o" KBL						Aksi permanen "x" KBU + beban aktif "x" KBU + 1 beban "o" KBL					

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3. Research Methodology

The procedures used in the study analyzes the failure factor suspension bridge consists of several stages which will be explained as follows.

3.1 Data collection

In conducting this analysis can no longer obtain primary data because the bridge had collapsed in a case study. So that, with a very forced this analysis is done by relying on secondary data only. In this analysis used a model that will be created by a computer program. This simulation requires a model that resembles the original so that the necessary pictures that give good information bridge dimensional images look, cut, detail size of each cross-section as well as the specifications of the material used.

3.2 Bridge Structure Modeling

Suspension bridge structure modeling using SAP2000 program. Configuration, size, cross-sectional shape and material specifications inputted into the program in accordance with the data obtained. Input configuration the overall structure of the bridge is done by importing images that have been done of the program AutoCAD. Then the boundary condition applied according to the actual situation as well ditambahnkan link element to represent the connection. After the model of the bridge loaded in accordance with the expenses incurred in the field and in the analysis of the service condition.

3.3 Component Analysis Connection Clamps

Focus rather than the analysis of the bridge structure is aimed at component connection between the cable clamps to the main cable hanger. Clamp connection component is made of a material that is unfamiliar used as structural components. In addition it also has a connection geometry peribahan sudden dimension. Sudden changes in the dimensions of the clamping connection has resulted in the effect of stress concentration and becomes a major factor in the collapse of the bridge.

3.4 Modeling and Analysis of Cases

After analysis of the condition of the bridge structure servicing conditions, cases that occur on bridges are analyzed one by one. The first is the case of shifting blocks haunted bridge, then slip clamp connections and leverage. Each case modeling and analysis done separately in a separate section. Analyses were performed separately to see the effect of each case on the bridge structure.

3.5 Simulation of Real Conditions

Having analyzed cases one by one and then do more analysis describes the situation in the field where all three cases occurred. Will be analyzed part of the most critical structural components to later be known whether the component failure triggers. Otherwise it would be expected to occur degradation of material quality and their effects on the overall structure of the bridge.

4. Results and Discussion

This study takes a case of failure of the suspension bridge in Indonesia that occurred several years ago, precisely on November 26, 2011. The bridge is Mahakam II Bridge or Bridge also called Kartanegara Kutai bridge that connects Tenggarong west and Samarinda in the east over the river Mahakam.

Here is the layout structure Kartanegara KutaiBridge

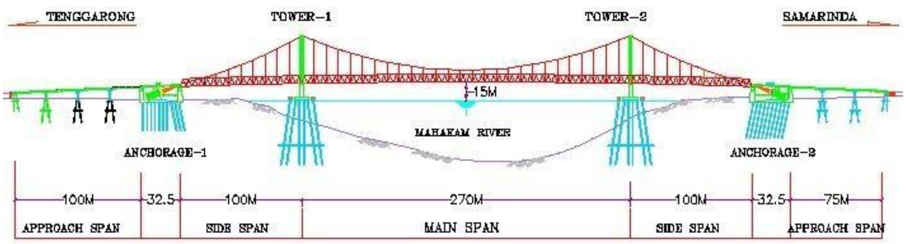

Fig. 4. Layout Kertanegara Kutai bridge structure from the downstream side

Here are the technical data commonly Bridge Kertanegara Kutai (source: Public Works Department of the Government of Kutai).

- Construction Type: Suspension Bridge
- Method of Construction: Heavy Lifting
- Floor System: Stiffening Girder Truss
- Vertical Clearance: 15 meters
- Horizontal Clearance: 270 meters
- Traffic Lane Width: 7 meters
- The pavement width: 1 meter
- Vehicle Clearance: 5 meters
- Load Off Bridge: 4260 tons
- Steel Frame Manufacturer: PT. Bukaka Teknik Utama
- Cable Manufacturing: from Canada (not called names)

To analyze the structure of Kertanegara Kutai bridge used SAP2000 structural analysis program assistance. Cable bridge element modeling involves a slightly different with the beam or truss element model that is familiar over the years. Cable element has properties of high nonlinear result of rigidity that is very sensitive to the force received.

Model bridge is done using SAP2000 program is a three-dimensional object of Trimatra.Of course the model it is thus obtained behavior is more akin to the original structure. Here are the results of the model bridge construction Kertanegara Kutai.

4.1 Stress analysis on the main cable

The maximum voltage that occurs in the main cable elements amounted to 359.7 MPa. The working voltage is compared with allowable stress main cable which has been discussed in the literature review chapter. To avoid a relaxing effect on the voltage occurring main cable must not be more than 45% of its voltage. Besides the main cable element must also have the power to cyclic load is good.

Cable tensile stress of 1860 MPa gives permission voltage of 837 MPa, so that the voltage that occurs eligible. Speaking about the collapse of the main cable of force against the safety factor

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obtained is equal to 5.17. Therefore it can be concluded that the structural elements of the main cable has sufficient strength.

The voltage changes that occur in the main cable is equal to 114.2 MPa. This voltage changes will be compared to voltage changes permitted by kakuatan fatigue. Voltage changes are allowed to be determined by the SN curve that has been developed for the cable bridge. Where the graph shows that the change in the allowable voltage is a function of the number of cycles that cause the material to fail. For the steel material commonly used value is equal to 106 cycles.

4.2 Analysis of the strength of the steel frame

The maximum voltage that occurs on a steel frame bridge is 272.7 MPa respectively on the rod press and 390.74 on the pull rod. According AISC, the safety factor that can be used is of 1.67. So the steel frame material that has a tensile stress of 490 MPa, tension permission be 293.41 MPa. It appears that the pull rod has sections in which the voltage exceeds the voltage permission. In addition, pull rod has undergone melting because it has passed the limit of 355 MPa yield strength. Excess voltage on the pull rod results of this analysis may occur due to the assumption of tower cross-section strap is too large to be more rigid than they should. Location rod press who experience extreme stress in the middle span of the bridge while the pull rod is experiencing extreme tension in strap tower placement

4.3 Analysis of strength hanger and its connection with the main cable

Maximum force that occurs on the wire hanger is at 681.27 kN. Hanger-hanger that experienced the greatest force is in the middle of the span. This is understandable because the area midspan is the farthest regions of the foundation pylons. Nature is not as rigid steel frame into the area that is close to the pedestal and also the greatest dafleksinya.

Hanger with a cross-section with a diameter of 63 millimeters are obtained voltage that occurs is the biggest hanger 218.55 on service conditions. This condition is very good considering that belongs hanger yield stress is equal to 555 MPa and a tensile stress of 700 MPa. The maximum voltage that occurs indicates the strength hanger is sufficient. Does not occur kelelehan and away from fault conditions.

4.4 Analysis of Structural Components Connection Clamps

When referring to the facts on the ground, then failure occurs almost entirely on the connection between the main cable hanger. the steel frame structure collapsed into the river along with a cable hanger and leaving only a few pieces. So it can be said clamping connection is the weak point of the bridge structure.

Clamp connection failure occurs in the hanging bar and the clamp half. Failure on the hanging bar clamp half ¬dan case with a sliding mode where these failure modes are brittle or sudden. Initial failure on the connection clamp hanger being in-jack lead to a deck that has been lifted to fall back resulting impact loads and cause progressive failure at all clamp connections.

4.5 Stress Concentration Factors Connection Pin Clamps

To determine stress concentration factor through graphic parameters required D/d the bar diameter ratio and r/d comparison with the fillet radius dimater smallest bar. This parameter is calculated in advance by reference to the following detailed pictures clamp connection.

Based on the above image detail induced stress concentration on the part marked with the letter 'x'. In the detailed geometry changes that occur are not accompanied by a gradual transition. Geomteri changes happen very suddenly without the slightest fillet radius. Therefore, when associated with a table that will be used the value of 'R' is zero. Where the fillet radius equal to zero will produce stress concentration factor infinite because the graph is the asymptotic

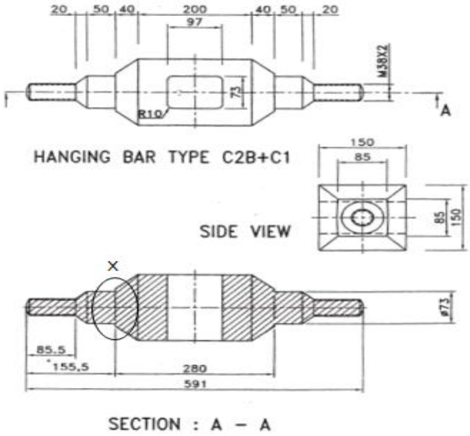

Fig. 5. Details clamp connection component parts hanging down bar

4.6 Collapsed capacity Material Connection Voltage Clamp

The material used for this clamp connection is material ferro casting ductile (FCD 600). In the specification it is said that this material has a minimum yield stress of 370 MPa and a tensile stress of 600 MPa minimum. However, in the fabrication of structural components are usually the real quality is higher than listed.

Based on the experimental results of static tensile test conducted by BPPT to the sample material obtained pin actual power is greater. Tensile test carried out on 3 pieces of samples are entirely derived from the original bridge connection pins. After the tensile test three have collapsed voltage above 600 MPa. When taken the average of the three test specimens the value of the material tensile strength is 668 MPa pin.

For the purposes of this study, in terms of checking the strength of the structure to collapse then the actual value is used in order to represent the actual situation. Against the axial tensile force and bending moments will be used to collapse the voltage limit 668 MPa. While under the influence of shear collapse assumed to occur at times of stress its 0.577 namely 385.67 MPa.

4.7 Case Analysis Shifting Block Angkur

Case of partial failure of the first bridge structure will be discussed is the shift of the armature block. Based on the information, there is a failure pile foundation on the side of the armature block Tenggarong resulting in the foundation is not able to withstand horizontal loads of cables is very large. The failure of this foundation blocks armature moves toward the center span of 15 cm.

4.8 Shifting Block modeling Angkur

In the previous chapter has discussed about the condition of the bridge structure in the service condition. From the model that has been analyzed is added modeling shift armature block. Shifting armature block will be modeled as a load transfer point at the end of the cable placement and steel frame Tenggarong side.

It needs to be conveyed is that the traffic load that is used is not based on ISO standard anymore but rather assumes the bridge suffered extreme possibility of traffic load in the form of a full queue of vehicles at midspan. Vehicles are assumed to have a weight of 4 tonnes so that total traffic load of

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360 tons. This applies to the entire analysis in this chapter. Here is input armature block shifting load

4.9 Block Shifting influence Armature

Here is a comparison of the results tabulation output analysis program SAP2000 in the analysis of the model of the bridge structure in normal service conditions and the condition of the armature block shifted or called Case 1.

Table 4. Comparison of the results of the analysis of the first case (unit Ton and mm).

	Normal	Case 1
Maximum hanger force	52,82	51,41
Press rod extremes	231,118	350,508
Axial rpd extremes	345,97	325,714
Maximum force main cable	1453,573	1386,274
Relative Deflection	-	248,087

Based on the table above shows that the displacement of the proportion of the burden among the components of the structure. It appears that the burden borne by the component wiring structure of both the main cable and the cable hanger is reduced. While the load received by the press on the rod steel frame becomes larger. Here we can see that there is a dependent displacement caused by the load shift of the armature block.

Midspan deflection bridge be increased as a result of this shift armature block. However, because this deflection becomes permanent so that the same characteristics deflection due to its own weight are not considered in terms of serviceability condition of the bridge. Further note that as a result of this decline was the rod press frame bridge into a receiving portion of a larger load. This is caused by the nature of the cable receiving only an axial tensile load so that if there is movement of the cable retracts it will lose the burden borne and transferred to the structural components capable of withstanding press. If the shift continues to be allowed to happen then the press rods may fail

In addition to the pull rod steel frame decreased force in the press due to the effects of the movement of the armature block toward the middle of the span. The voltage that occurs at the pull rod amounted to 252.3 MPa at normal conditions fell to 237.54 MPa. Whereas the compressive stresses occurring stem is 168.1 MPa rose to 254.94 MPa where voltage limits permits allowed is 293.41 MPa. It can be said that the steel frame was still safe in these circumstances.

Then to the maximum voltage that occurs on the cable hanger amounted to 166.055 MPa at normal conditions and 161.623 MPa on condition of armature block shifted. These voltages are still quite far from the limit of 555 MPa hanger melting material. For the main cable tension that occurred amounted to 283.768 MPa and 270.630 MPa service condition at the time of the shift. This condition is still below the main cable voltage limit of 0.45 times the voltage collapse, 837 MPa.

Conclusions from the analysis of the first case of this is a failure that resulted in the shifting foundation armature block this does not imply the failure of structural components of the bridge as well as the overall structure. With this shift notes stopped at number 150 mm.

4.10 Slip Case Analysis Connection Clamps

The next case to be discussed is the shift or slip clamp connection between the main cable and the cable hanger. In this case the modeling is done twice with different methods. The first by modifying the link so that the location of the connection clamps move. Then, by moving directly node models meetings with major cable clamp connection. Slip clamp connections in the field can occur as a result of static friction force has been exceeded by the force of the hanger. This may occur as a result of a decrease in the quality of materials such as rust or Letting bolt fasteners

4.11 Analysis of Collapse of bridge

The present analysis attempts to portray the real situation happening on the ground comprehensively. Bridge aquatic mammal can experience all three events above and even according to the information it happen. Therefore, it will be seen how perngaruhnya if the three cases occurred together on the model bridge.

For the second case or melorotnya clamp connection will be used first modeling the modeling using a modification of an additional link. Events that occur in the field is the accumulation of many factors that may not be considered in this paper. As in this study considers the strength of the material connection clamps and other components are not reduced at all. Later the results obtained may not indicate a failure due to the exclusion of other influences. Therefore, the results obtained will be estimated material degradation that occurred and also analyzes why the structure to collapse progressively.

At this simulation leverage or jacking will be done gradually and alternately between the hanger number 13 in the upstream and downstream. Each jacking is done by jack stroke by 5 cm each hanger. Exodus program will be recorded every jacking and made up jacking the upstream reaches 10 cm and 15 cm downstream. The analysis will be conducted prior to the hanger clamp connection that is being jacked. Results of the analysis are presented in the following table.

Table 5. Tabulation analysis due to jacking on both sides.

JACK STROKE		REL. MC DISP		REL. GIRDER DISP		ABS MC-GIRDER DISP RATIO		HANGER FORCE	
Up stream	Down Stream	Up stream	Down Stream	Up stream	Down Stream	Up stream	Down Stream	Up stream	Down Stream
0	0	-	-	-	-	-	-	51.28	51.28
0	5	1.676	-43.93	1.683	4.456	0.996	9.859	51.23	63.22
5	5	-42.256	-42.256	6.138	6.137	6.884	6.885	63.16	63.16
5	10	-40.342	-85.68	8.06	11.094	5.005	7.723	63.1	75.14
10	10	-83.769	-83.77	13.015	13.015	6.436	6.436	75.07	75.07
10	15	-81.619	-126.68	15.177	18.474	5.378	6.857	74.99	87.1

At the end of jacking it appears that the style hanger that occurs less than earlier cases where jacking is only done on one side. In terms of the appointment of the deck is also higher, reaching 18.474 millimeters downstream side compared with the previous cases about 15 millimeters. The fall in the main cable also reduced so that the ratio of the movement of the main cable and the deck is getting

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down. This is understandable because this time the burden borne by the deck appointment of two main cable.

In the previous analysis obtained hanger greater force and through analysis that takes into account the effects of stress concentration is still not a failure occurs. This time it showed that it is smaller that 87.1 tons in the hanger number 13 in the downstream. And in the field that happens is that progressive structural failure and started from a connection failure hanger that is being jacked. This means that there has been a degradation of the material on the pin clamp connection.

Based on this fact will be estimated how large a cross-section pin connection that has been degraded. Keep in mind that a failure occurs in a shear mode. Using the results of the static tensile test as a reference the shear failure occurs at a voltage of 385.67 MPa. While the hanger style produces 87.1 tons of 329.368 MPa shear stress.

The possibility of material degradation that occurs is corrosion and cracking due to fatigue, or fatigue. Factors that affected so here is a cross-sectional area effective in resisting shear pin is reduced. Behind obtained through the calculation of degradation that occurs in a cross-pin is 14.6%. Resulting in the failure of the connection pins there are several factors that lead to the leverage, the concentration of stress and material degradation.

Failure hanger number 13 downstream have implications long. This resulted in the failure of the bridge deck hanger raised fallen back and resulting impact loads on other structural components. Allegedly preceded the collapse of the downstream addition to the larger style pattern collapse occurs when referring back to Figure 5.3, the collapse occurs downstream connections in total and symmetrical while upstream collapse appears to have rambang pattern.

Impact loads that occur due to failure of the first experienced by the hanger to the left of the right hanger numbers 12 and 14 downstream. Wherein each hanger style shortly before the collapse is 18.32 tons and 33.7 tons. Assuming the amplification of the load from the effects of shock or impact of 1.5 then the smaller hanger the hanger style number 12 will assume a force of:

Style hanger 12 on impact = 1.5 × (18.32 + 87,1/2) = 92.325 tons

Hanger style number 12 has exceeded the load collapsed hanger number 13. Assuming a cross-section hanger connection pin number 12 is also experiencing the same problem then the failure of the pin, too. Finally, creating a domino effect failure clamp connection between the main cable and the cable hanger. Created a domino effect in the longitudinal direction and towards the upstream side so that almost the entire clamp connection fails and no longer able to withstand the deck of the bridge and fell into the river.

5. Conclusions and Recommendations

5.1 Conclusions

Based on the results of studies that have been conducted on the case of the collapse of the bridge aquatic mammal can be drawn several conclusions:

1. Structure Bridge of Kartanegara Kutai has sufficient strength in normal servicing burden.
2. Shifting the armature block bridge resulted in the removal of the load proportion of tensile elements to alemen press and deflection increasing midspan but the condition of the bridge is still safe.

3. The occurrence of slip on the connection clamps resulted in a redistribution of the burden of sagging hanger to hanger or strap tower located right next to it. The addition of the expenses incurred are still within safe limits.
4. everage carried on the hanger at midspan cause a significant increase in force. Leverage ineffective in raising the elevation of the bridge deck, instead of the main cables were down. Leverage on one side of the jack stroke 15 cm resulting in a voltage close to the voltage collapse when analyzed by considering the effect of stress concentration.
5. Geometry clamp connection on the connection pin has a sudden change causing stress concentration effects. Due to the stress concentrations arising voltage multiplier effects that occur. Bending stress concentration factor at the pin clamp upper half of 2.2 and to the shear stress of 3.23.
6. In the case in the field where the movement of the armature block, slip joint and jacking process is carried out on the hanger, hanger style that happens is 87.1 tonnes on the downstream side in the jack 15 cm and 75 tonnes on the upstream side which is expandable to 10 cm of hanger style beginning at 51.28 tons. Should not have been a failure occurs.
7. Failure happens on the field may indicate a decrease in the quality of material due to corrosion and cracking due to fatigue. Failure happens on the field is The failure shear. This failure can be caused by a reduction in the effective cross-sectional area by 14.6% pins.
8. Failure on a single hanger resulting impact loads by a factor of 1.5 is assumed to impact loads. As a result of impact loads clamp connections that others do not withstand the load and a domino effect of this component failure. Finally, the bridge deck could no longer hold and fell into the river.

5.2 Recommendations

Advice can be given to these events is:

1) In the aspect of planning the use of materials ferro casting ductile (FCD 600) should not be on such an important component of a clamp connection. The nature of this material is less ductile or brittle and low impaknya resistance.
2) Planning geometry clamp connection should not give the dimensions of the sudden change. Clamp connection dimensional change must direncang with certain minimum fillet radius to avoid the effects of stress concentration.
3) In the aspect of maintenance should be performed structural analysis to determine the appropriate methods in relation to the bridge camber adjustment process. Leverage process is done in the middle of the span proved to be ineffective and even lead to failure.
4) The treatment process should be conducted regularly in order to avoid degradation of material strength due to corrosion or due to other causes.

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