Analysis of Bridge under Construction Collapsed by 2012 Thabeikkyin Earthquake in Myanmar

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The Yadanatheinkha bridge under consturuction is collapsed due to the Thabeikkyin earthquake happened on 11 November 2012 in Myanmar. Only the superstructure of the Yadanatheinkha bridge under constructure is considered in this study. Static analysis of the Yadanatheinkha bridge under constructure and dynamic analysis due to El Centro 1940 earthquake are carried out by numerical analysis using OpenSees software. Firstly, the king post is neglected to check the performance of the bridge structure under construction without supporting of the king post and only the weight of all structural members of the bridge truss and traveler crane are considered in the analysis. Then, the Yadanatheinkha bridge under construction with supporting of the king post is analyzed to realize the importance of the structural control of the king post for the during construction stage bridge and the weight of all structural members, traveler crane and king post are considered for the analysis. The stability of the bridge under construction is checked for both cases.

Key Words : *bridge under construction,collapse,earthquake, static and dynamic, the king post, stability*

1. INTRODUCTION

Myanmar is in a seismically active part of the world where the Indo-Australian Plate runs up against the Eurasian Plate. Geographically, a larger part of Myanmar lies in the southern part of the Himalaya and the eastern margin of the Indian Ocean, hence exposed to bigger earthquakes and is earthquake prone as it lies in one of the two main earthquake belts of the world, known as the Alpide Belt that starts from the northern Mediterranean in the west, and then extends eastwards through Turkey, Iran, Afghanistan, the Himalayas, and Myanmar to finally Indonesia.

The historical and seismic records show that in addition to some major historical earthquakes in the distant past, there had been at least 17 large earthquakes with M 7.0 within the territory of Myanmar in the past 170 years[1)]. Among these, the following four and 1975 Bagan Earthquake arranged chronologically, were quite destructive: Innwa (Ava) earthquake of 23 March 1839 (M > 7.0), Maymyo earthquake of 23 May 1912 (M 8.0), Bago (Pegu) earthquake of 5 May 1930 (M 7.3), Sagaing earthquake of 16 July 1956 (M 7.0), and Bagan earthquake of 8 July 1975 (M 6.8).

In very recent years, magiutde of 6.8 happened Thabeikyin earthquake of November 2012 and resulted the death toll 26, missing 12 and 231 injured. 201 houses, 25 schools, 13 hospitals and clinics, 35 monasteries and 45 pagodas were totally collapsed or partially damaged. Due to this earthquake, the huge economy losses for society is that Yadanatheinkha bridge under construction which is located in Kyaunk Myaung Township, Shwebo District, Sagain Region collapsed and 2 deaths and 25 injuries from the Yadanatheinkha bridge collapse.

The 6.8MWP magnitude earthquake, the U.S. Geological Survey (USGS) estimated, near the town of Chauk, on the Ayeyarwaddy River south of Bagan and about 175 km southwest of the Mandalay city on August 2016 caused severely damage ancient temples at the old city of Bagan and 185 pagodas and temples in Bagan, nine in Salay region, three in Mrauk U and seven in Sagaing were damaged and Pagodas and other buildings in Mandalay, Rakhine and Magway showed cracks and two deaths occured in the Yenangyaung township, and two in the Pakokku township. This earthquake caused the most destructive of the historic monuments in Myanmar.

(1) Plate tectonics and seismotectonics

For about the last 140 million years (since early Cretaceous times) the Indian plate has been moving northward towards Eurasia, and continues to do so today. For about the last 50 million years its northward motion has resulted in the formation of the Himalayan mountains and uplift of the Tibet plateau.

As India continues to push northwards into Eurasia at 35mm each year, its eastern margin slides obliquely sideways past SE Asia along a complex and diffuse plate boundary beneath. The oblique motion is split (or partitioned) into two components:
(a) East-directed plate convergence and resultant uplift in the Indo-Myanmar mountain ranges,
(b) Sideways, (or strike-slip) motion whereby India moves north relative to SE Asia.

The strike-slip motion is itself divided between a numbers of structures. The most significant is the Sagaing Fault, a 1500 km long tectonic fault that passes through the cities of Nay Pyi Taw, Bago, Sagaing and Mandalay, and close to Yangon.

Due to the continued Northward subduction of the Indian Plate underneath the Burma Platelet (which is the Western part of the Eurasian Plate) and the Northward movement of the Burma Platelet from a spreading center in the Andaman, earthquakes in Myanmar have resulted from three major seismotectonic regimes as follows;

(i) Sumatra-Andaman Subduction Zone to the West of the Myanmar coast. In detailed classification, three separate portions of seismotectonic setting can be distinguished as follows. (a) The Sumatra-Andaman Inter Plate where shallow-focus earthquakes are normally generated along the trench, (b) the Sumatra-Andaman Intra Slab that is bounded by the occurrence of intermediate to deep-focus earthquakes underneath the Western fold belt of Myanmar, and (c) the portion of the Western fold belt that we call the “Arakan Yoma Thrust Range” where compressive tectonic activity, that is, reverse faulting, usually causes shallowfocus earthquakes.

(ii) Major active strike-slip fault along the Central lowlands of Myanmar. Beside the Sumatra-Andaman Subduction Zone, Myanmar has a great strike-slip active fault zone called the “Sagaing Fault Zone”. This 1,200 km-long fault trends roughly North-South and moves right-laterally with a velocity of 23 mm/yr.

(iii) Regional shear zone in the highlands of Eastern Myanmar. This seismotectonic regime is continuous with the earthquake zones in Southern China, North-Western Laos and the Northern and Western part of Thailand[2)].

Tectonically, the Himalaya orogeny is still an active process producing earthquakes in various magnitudes and its southern extension, the western Myanmar region is also seismically active due to the collision between the India and Burma plates where both shallow and intermediate earthquakes are frequent. The tectonic map of Myanmar is shown in **Fig. 1**[3)].

The major seismotectonically important faults in Myanmar are some unnamed major thrust faults in north-western Myanmar, Kabaw Fault along the Kabaw Valley in western Myanmar, the well-known Sagaing Fault, and the Kyaukkyan Fault situated west of Naungcho. The well-known and seismologically very active Sagaing Fault is the most prominent active fault in Myanmar, trending roughly north-south. It has been an originator of a large proportion of destructive earthquakes in Myanmar. This is due to the fact that many large urban centres lie on or near this fault. In fact, of the five major source zones in Myanmar, three lie around this large and dangerous fault. It is a right lateral strike-slip fault extending from south of Putao, west of Katha, through Sagaing, along the eastern flank of Bago Yomas, then through Bago, and finally into the Gulf of Mottama for a total distance of about 1500 km.

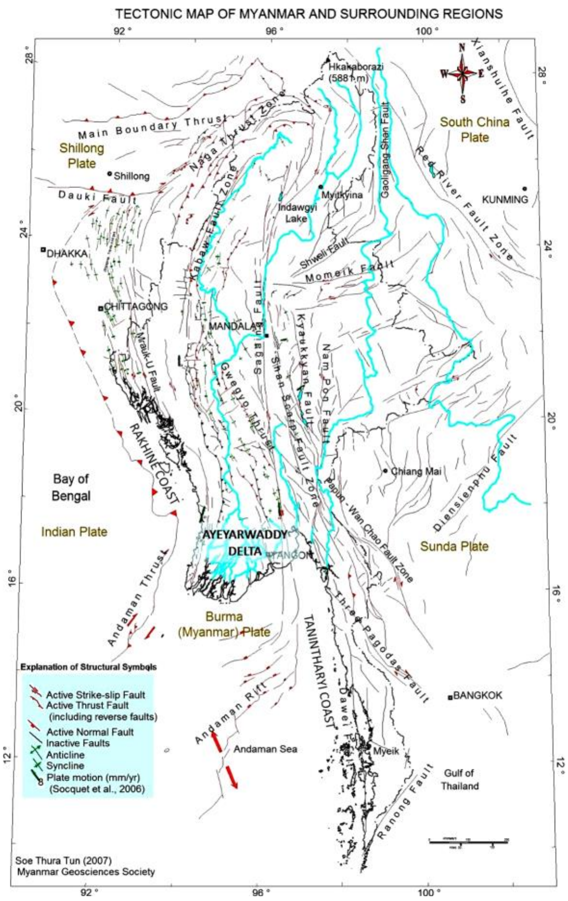


Fig. 1 Tectonic map of Myanmar and surrounding regions[3)]

The Sagaing fault links two very different, but equally active tectonic domains: the Andaman Sea in the south and the eastern Himalayan syntaxis in the north. The Sagaing fault has similarities with other active strike-slip faults around the world, such as the San Andreas Fault, USA, the Enriquillo-Plantain Garden Fault Zone, Jamaica-Haiti, the Palu-Koro Fault, Indonesia, and the Dead Sea Fault in the Middle East.

(2) Historic earthquakes along the Sagaing Fault

A narrow zone of seismicity that is generally shallow in the west and deep (up to 600 km) in the east extends from the Sumatra trench north to the Andaman Trench and below western Myanmar. These earthquakes are associated with the oceanic part of the Indian plate that has been subducted into the Earth's mantle. The characteristic zone of seismicity dipping into the mantle is called a Wadati-Benioff zone, and can be found in most subduction zones around the world. More diffuse shallow seismicity, including earthquakes associated with the Sagaing Fault, occurs in the upper part of the crust throughout Myanmar and into the Tibet plateau. Like most active tectonic faults, the Sagaing Fault releases accumulated strain in spasmodic and unpredictable slip events associated with earthquakes. Locations of the last ten years of earthquakes greater than magnitude 4 for the region are shown in **Fig. 2**. The Sagaing fault has a long recorded history of seismic activity as shown in **Fig. 3.** Like other similar structures, the Sagaing fault fails along segments, with a M 7.5 earthquake typically rupturing a 150 km long segment. Failure of one segment during an earthquake can change the stress field around adjacent segments, making them more likely to subsequently fail[4].

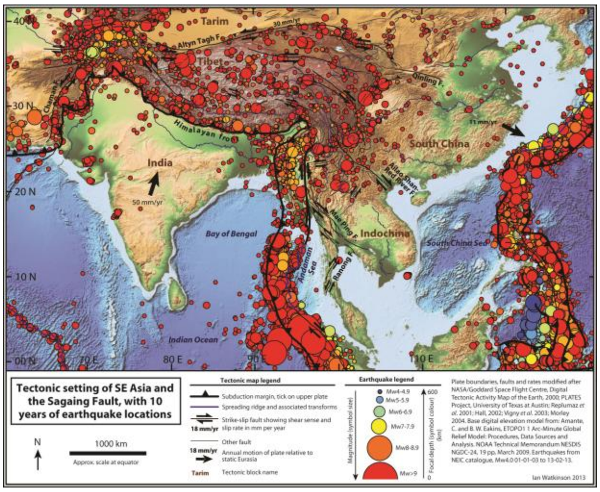


Fig. 2 Earthquake locations from 2003 to 2013, from USGS NEIC catalog[4]

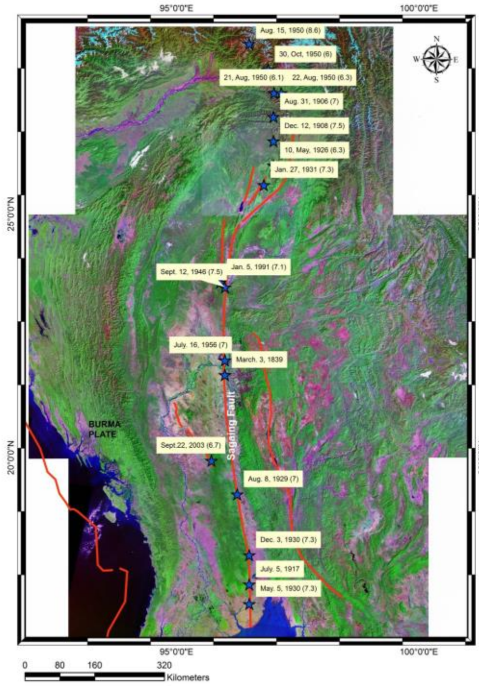


Fig. 3 The epicenters of significant earthquake along the sagaing fault

(3) Seismic zoning map of Myanmar

The first seismic zone map of Myanmar prepared by Dr. Maung Thein, Dr. Sone Han, U Tint Lwin Swe and Daw Tin Htay Mu in August 2003 and made revised by Dr. Maung Thein, U Tint Lwin Swe, and Dr. Sone Han in December, 2005 under Myanmar Earthquake Committee in coopration with Myanmar Geosciences Society.

The seismic zoning map is preapered based on the seismic and seismotectonic data and information together with some inferences such as (1) Regional and local seismotectonics with special reference to major active faults, (2) Past earthquake data, records, and information including intensity maps in MM scale, if available, (3) Distribution and density of earthquake epicenters with $M \geq 5.0$ and (4) spatially correlated peak horizontal ground acceleration (PGA) computed for various seismic events. These information leads to the delineation of at least five seismic source zones (Seismogenic Zones). These are

(1) northwesternmost Myanmar zone,
(2) Mandalay -Sagaing-Tagaung zone,
(3) Bago-Taungoo zone,
(4) northern Shan- southern Yunnan zone, and
(5) northern Andaman Sea zone.

The map is a probable intensity zoning map. The approach is mainly empirical and historical in the sense that it makes use of past seismic events and history. The seismic zoning map of Myanamr is shown in **Fig. 4**[5]. As shown in **Fig. 4**, five seismic zones are demarcated and named (from low to high)

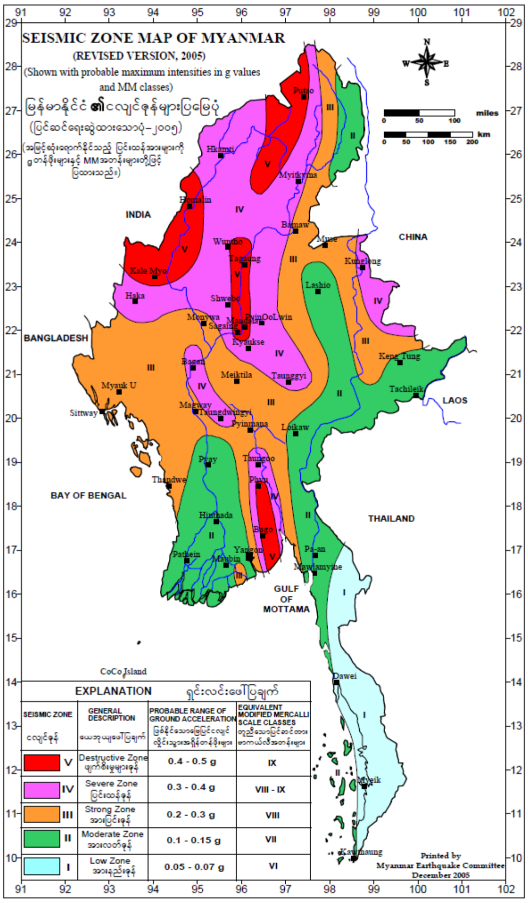


Fig. 4 Seismic Zone map of Myanmar[5)]

Zone I (Low Zone), Zone II (Moderate Zone), Zone III (Strong Zone), Zone IV (Severe Zone), and Zone V (Destructive Zone), mainly following the nomenclature of the European Macroseismic Scale 1992. For each zone, a probable range of ground acceleration in g values and equivalent Modified Mercalli (MM) Scale classes are given. The highest intensity zone designated for Myanmar is the Destructive Zone (with probable intensity range of 0.4 – 0.5 g) which is equivalent to MM class IX. There are four areas in that zone; namely, Bago-Phyu, Mandalay-Sagaing-Tagaung, Putao-Tanaing, and Kale Myo-Homalin areas. The latter two, however, would not have major earthquake hazards as they are only sparsely populated.

Important cities and towns that lie in Zone IV (Severe Zone, with probable intensity range of 0.3 - 0.4g) are Taungoo, Taungdwingyi, Bagan-Nyaung -U, Kyaukse, PyinOoLwin, Shwebo, Wuntho, Hkamti, Haka, Myitkyina, Taunggyi, and Kunglong. Yangon straddles the boundary between Zone II and Zone III, with the old and new satellite towns in the eastern part in Zone III, and the original city in Zone II. Regarding the probable range of ground acceleration (in g values; where 1.0 g = 980 cm/s2 or 32 ft per second per second) expected in various seismic zones, it should be noted that the range of g values

Table 1 Damage level for different seismic zones[5)]

Zone	MM Classes	Probable Damage	Examples of Damage
V	IX	Major damage	Considerable damage in specially designed structures Major damage in good RC buildings
IV	VIII – IX	Considerable damage	Considerable damage in good RC buildings Major damage in ordinary brick buildings
III	VIII	Moderate damage	Moderate damage in good RC buildings Considerable damage in ordinary brick buildings
II	VII	Minor damage	Minor damage in good RC buildings Moderate damage in ordinary brick buildings
I	VI	Slight damage	Minor damage in ordinary brick buildings

given for a zone is for those places with soft and medium stiff soils in an affected area - in general, the higher value is for soft soils, and the lower value is for medium stiff soils; the g value will be lower for other places with stiff soils or bedrocks[5)].

The average g value in the various seismic zones may be taken as the "zone factor" of ground acceleration. Thus, the zone factors would be 0.065 g, 0.125 g, 0.25 g, 0.35 g, and 0.45 g for Seismic Zones I, II, III, IV, and V, respectively. Regarding the Modified Mercalli (MM) Scale classes, the level of probable damage and destruction are summarized as in **Table 1**[5)].

2. THABEIKKYIN EARTHQUAKE

A 6.8 magnitude earthquake happened on 11 November 2012 epicenter at 95.883°N, 23.014°E, 9.8 km (depth), that is 45 miles from North of Shwe Bo Township, Sagaing Region and 100 km north of Mandalay, Myanmar, and in the place of the Thabeikkyin, close to the trace of the Sagaing fault at a depth of about 10 km. Ground shaking affected much of the central part of the country, and a 45 km long surface rupture formed along the trace of the Sagaing fault. Two large aftershoks of magnitude of 5.8 and 5.6 and a series of small aftershocks followed after the 11th November Thabeikkyin earthquake. Focal mechanism of the main shock and two largest after shocks is shown in **Fig. 5**[6)].

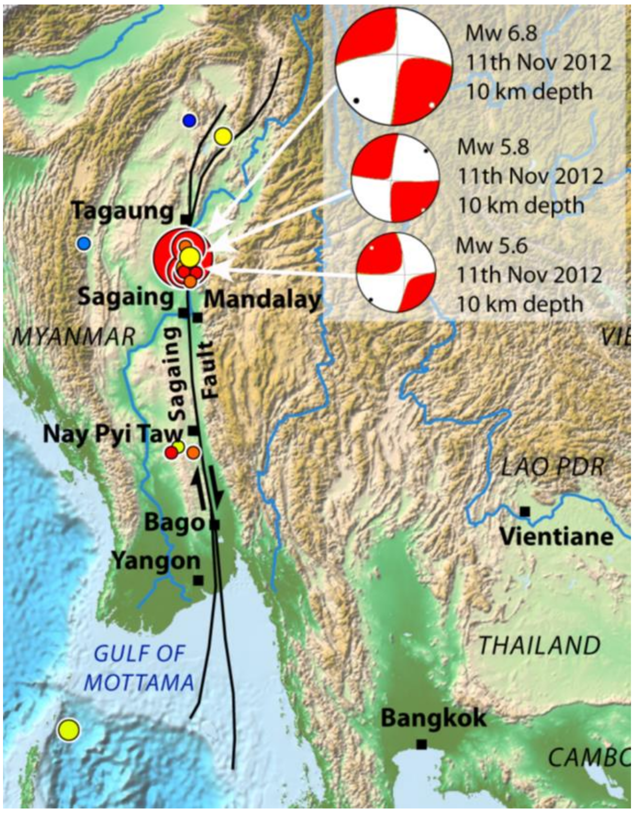


Fig. 5 Seismicity associated with the Thabeikkyin earthquake NEIC seismicity from 10th November to 18th December 20126)

It show the geometry of the fault that caused an earthquake by plotting the first motions of P waves, i.e. towards or away from the source, from seismographs at many seismic stations. The 'beachball' diagrams on the map below are stereographic projections of these data. Size is proportional to magnitude, colour is proportional to hypocentral depth, red ≤ 10 km, yellow is up to 30 km, and blue is ≥ 40 km. Due to the Thabeikkyin earthquake, about 26 people lost of lives, 12 missing and over hundreds of housings, hospitals, ministries and pagodas were severely damaged. Among the damages and losts, the huge economically lost for engineering society is the under construction stage bridge "the Yadanatheinkha" with 1162 tons was under water and severely collapsed due to the earthquake.

3. YADANATHEINKHA BRIDGE

The Yadanatheinkha bridge is located in Kyauk Myaung Township, Shwebo District, Sagaing Division, northwest of Mandalay, Myanmar. Yadanatheinkha bridge is 756m long including two approaches at each end, three continuous two spans, truss bridge and 8.5m wide for two ways road for cars. The approach road in Sint Koo side is 60m long and in Kyauk Myaung side is 20m long. It connects Sint Koo Township in Mandalay division and Kyauk Myaung Township in Sagaing Division. The Yadanatheinkha bridge profile is shown in **Fig. 6**. The Yadanatheinkha bridge considered for the analysis is during construction stage condition just before the 11th November 2012 Thabeikkyin earthquake.

At the construction stage of the bridge, all the foundations and piers of the whole bridge were already construted and one span of 112m long and another span of 96m long just before arriving the next pier of the truss of the superstructure of the bridge were constructed. One span was already constructed and the next span is situated as the cantilever. Only the superstructure of the bridge is considered for the analysis because almost the whole truss strucutre are totally collapsed due to the severe Thabeikkyin earthquake. The superstructure of 3D bridge under construction of 208m long and 10.2m width for calculation for analysis are considered. The portion of the superstructure of the bridge under construction considered for the analysis is as in red color portion of the bridge that is already finished just before the Thabeikkyin earthquake shown in **Fig. 6**. The actual condition of the Yadanatheinkha bridge during construction stage condition considered for the analysis just before the Thabeikkyin earthquake is shown in **Fig. 7**.

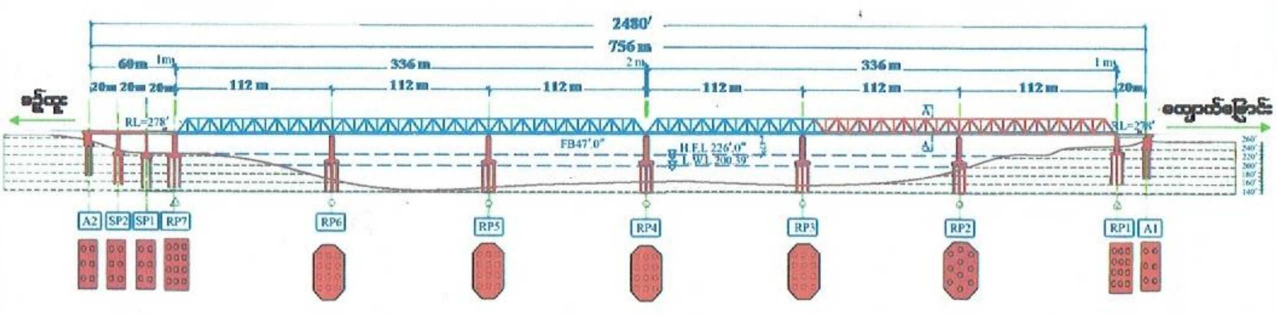


Fig. 6. Yadanathinkha bridge profile

Fig. 7 Yadanatheinkha bridge under construction just before the Thabeikkyin eartquake

(1) Collapse of bridge in Thabeikkyin earthquake

The Yadanatheinkha bridge under construction is damaged because of the 11th November Thabeikkyin earthquake of 6.8 magnitude. The collapsed of the bridge due to the earthquake is shown in **Fig. 8**. The bridge with the weight of 1162 tons being under construction was failed into the river and the truss structure was totally collapsed due to the earthquake. Six workers lost of lives, 18 workers were injuried and approximately total amount of 1.92million US$ lost and we have the huge economic impact because of that event.

The numerical static and dynamic analysis due to El Centro 1940 earthquake of the Yadanatheinkha bridge under construction condition is carried out by using OpenSees software. The support of the king post is neglected first to check the behavior of the bridge for the numerical analysis without the supporting of the king post during construction of the bridge. The compressive and tensile stresses of the critical members of the truss and the displacement of the top chord of the cantilever truss are checked and compared with the respective allowable values.

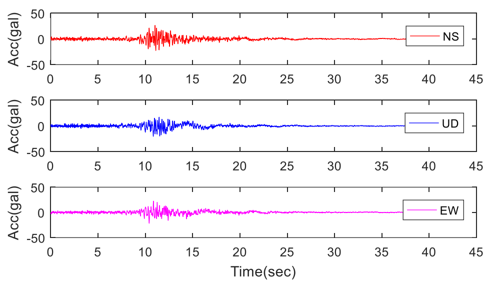
Fig. 8 Collapse of the Yadanathinkha bridge due to the Thabeikkyin earthquake

Then, the supporting of the king post to the bridge is considered for the numerical analysis of the bridge under construction to know the important of the supporting of the king post to the construction of the bridge.

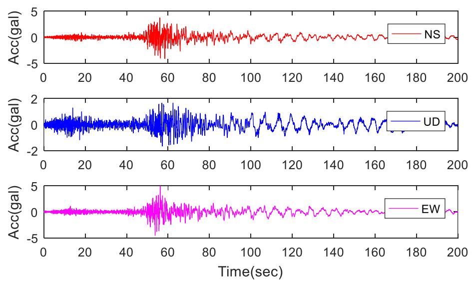
a) Strong groung motion record

The strong ground motion record of the Thabeikkyin earthquake is collected at Mandalay and Naypyitaw Stations, Myanmar. Mandalay station is situated at 20.016°N, 96.112°E and Naypyitaw station is at 19.7787°N, 96.1376°E. The locations of the epicenter of the Thabeikkyin earthquake and two seismic stations are shown in **Fig. 9**. The earthquake time history of the Thabeikkyin earthquake at Mandalay and Naypyitaw stations are shown in **Fig. 10**. The peak value of the earthquake at the Mandalay station is 26.4gal in N-S direction and at the naypyitaw station is 5.0gal in E-W direction.

Fig. 9 Locations of epicenter, bridge site and two seismograph stations



(a) Strong motion record at Mandalay station



(b) Strong motion record at Naypyitaw station

Fig. 10 Earthquake time histories of Thabeikkyin earthquake

4. NUMERICAL ANALYSIS

The numerical analysis of the Yadanatheinkha bridge under construction is carried out by using OpenSees software. 3D Static and dynamic analysis of the bridge under construction is done without and with supporting of the king post. The steel material Q345C is adopted and has the yield strength of 345Mpa. In the analysis, only the superstructure of the bridge is considered. In the numerical analysis, all the members of the truss are modeled as the elastic beam column elements considering that the bridge analysis in earthquake engineering research, all the structural elements of the superstructure level of the bridge tends to remain elastic. The supports are set up at the locations of the four piers. In the numerical model of the structure for the analysis, the axis along the bridge structure in longitudinal direction is considered as x-axis, the vertical direction is y-axis and across the bridge in the transverse direction is z-axis respectively. The model for the analysis is shown in **Fig. 11**.

In the case of without supporting of the king post, only the weight of all members of the truss and the weight of the tranveller crane are considered for the analysis. All the load and weight of the members are applied at each node of the members and the traveler crane weight are equally applied at the three nodes of the upper chord of the cantilever truss where it is actually located. In the case of with supporting of the king post, the weight of all members of the truss, the tranveller crane weight and the weight of the king post are considered. The weight of the king post is exerted at the node point of contact between the king post and the top of the truss. The connection between the king post and truss members are considered as hinge connection as same as the actual condition of the king post and assigned in the model as moment release about z-axis in the transverse direction of the truss structure. 3D models the bridge without and with supporting of the king post are shown in **Fig. 12**.

(1) Simplification of the king post

For the numerical analysis of the Yadanatheinkha bridge with supporting of the king post, the configuration of the king post used for construction after the earthquake is simplify to rectangle shape as same area as the tower column of the actual king post for the whole one for the simplicity and because of the data difficulties of the actual size of all members of the king post and dimensions, considering as close as to the actual configuration of the king post used for construction before the earthquake. All the original and simplified configurations of the king post are shown in **Fig. 13**. The actual king post used for construction before the earthquake is as in **Fig. 13** (a) and the king post used for construction after the earthquake is in **Fig. 13** (b) and the simplification of the king post is shown in **Fig. 13** (c). The tension rods connecting from the top of the king post to the truss members are four 160 mmϕ at each side of the two column of the king post as same as the actual size of the tension cables during the construction. All the king post towers and tension cables are modeled as the elastic beam column elements for the analysis.

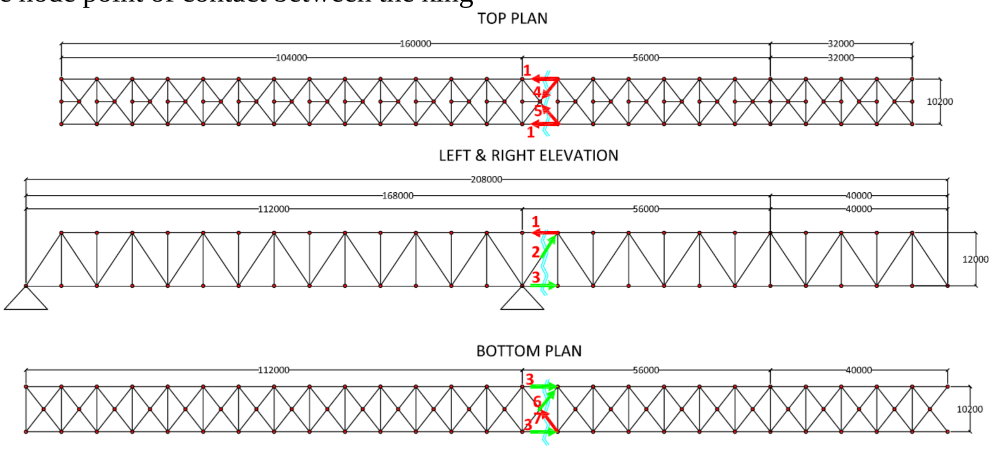
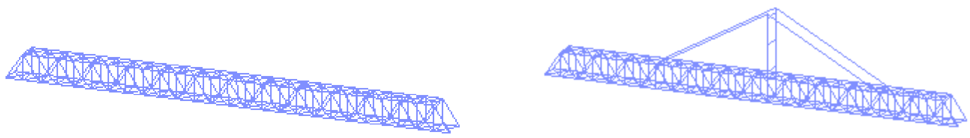


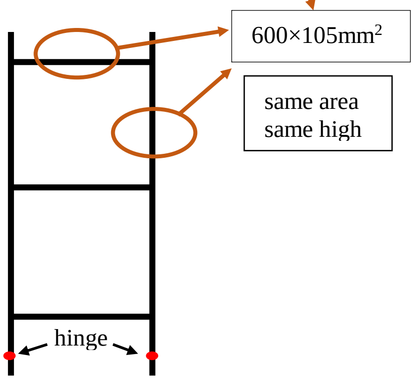
Fig. 11 Model for numerical analysis



(a) 3D model without supporting of the king post (b) 3D model with supporting of the king post

Fig. 12 3D model of the bridge without and with supporting of the king post

(a) King post used before earthquake (b) King post used after earthquake



(c) Simplified king post frame for analysis

Fig. 13 King post figure simplification

(2) Static analysis

3D Static analysis of the Yadanatheinkha bridge under construction without and with supporting of the king post are carried out by numerical analysis using OpenSees software. During the static analysis, only the gravity loads are considered. In the first step, the king post is neglected to check the behavior of the structural members of the truss during the construction of the bridge. Without supporting of the king post, only the weight of all members of the truss, the traveler crane weight are considered. The results obtained from the numerical analysis of the model are compared with the results from 3D hand calculation of the truss to verify the validality of the numerical analysis. The results from numerical analysis are close to those of 3D hand calculation although it has small difference for the top and bottom chords of the truss. The tensile and compressive stresses of the critical members adjacent to the supports of the cantilever truss are obtained from the numerical static analysis and compared with the allowable compressive and tensile stresses. The critical members are arefered to as in **Fig. 11**. The allowable axial tensile stress is assumed to be 60% of the yield strength of the steel member (0.6Fy). The allowable axial compressive stress is the minimum value obtained from flexural buckling and flexural torsional buckling according to AISC-ASD89. In the static analysis without supporting of the king post, although the tension members at the top chord and the compression members at the lateral bracing have the enough capacity to resist the applied loads, some compression members at the bottom chord of the truss failed to resist the load and those of stresses exceeds the allowable compressive stress.

When the truss structure is supported with the king post during the construction, all the truss members can successfully withstand the weight of the members and the stresses of all tension and compression members are obviously lower than allowable stresses and that of without supporting of the king post. The stresses of the tension and compression members of the critical members of the truss for the static analysis without and with the support of the king post are compared as shown in **Table 2**. The positive sign of the stress in Table 2 refers to the stress for the tension members and the negative sign refers to the stress for the compression members. The stresses for the critical tension members without supporting of the king post are 7 to 44 times larger than that of supporting of the king post and for the compression members are about 5 to 23 times larger than that of supporting of the king post.

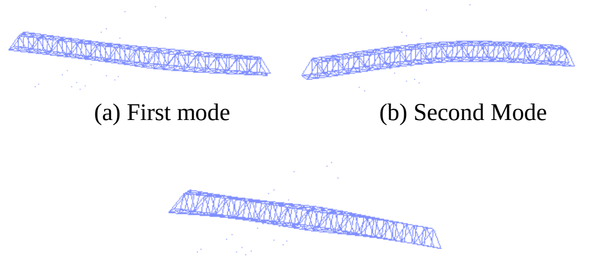
Seeing from the analysis, we can understand that the supporting of the king post provides the safety of the bridge construction to prevent the failure of the structure under the gravity load.

(3) Eigen value analysis

Eigen value analysis is important to determine the dynamic parameters of the structures such as the natural frequaencies and mode shape which characterized the dynamic behavior of the structure and how the structure will response the dynamic loading. The modes of the 3D truss of the bridge under construction are calculated. The first three modes of the

Table 2 Results of static analysis of the Yadanatheinkha bridge without and with supporting of the king post

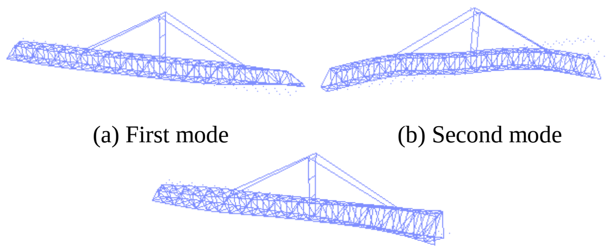
Member	Area (mm^2)	Stress (Mpa) (static analysis)		Allowable stress (Mpa)
		without king post	with king post	
1	46320	172	3.89	207
2	43168	-26.6	-5.72	-69.5
3	38904	-172	-25.0	-93
4	7200	19.9	0.87	207
5	7200	-19.9	-0.87	-71.1
6	7600	-35.5	-5.19	-72.6
7	7600	35.5	5.19	207



(a) First mode (b) Second Mode

(c) Third mode

Fig. 14 First three modes of 3D truss without supporting of king post



(a) First mode (b) Second mode

(c) Third mode

Fig. 15 First three modes of 3D truss with supporting of king post

truss without the supporting of the king post are shown in **Fig. 14** and the first three natural frequencies are 0.630Hz, 0.646Hz and 1.026Hz and periods are 1.588s, 1.547s and 0.975s respectively. The fundamental mode of vibration of the bridge without supporting of the king post is in the transverse direction due to El Centro 1940 earthquake.

The first three mode shapes for the bridge with the supporting of the king post are shown in **Fig. 15**. The first three natural frequencies are 1.309Hz, 1.767Hz and 1.916Hz and periods are 0.764s, 0.566s and 0.522s respectively. The dominant mode of the vibration of the bridge with supporting of the king post corresponds to the transverse direction of the bridge according to the dynamic analysis due to El Centrol 1940 earthquake.

(4) Preliminary dynamic analysis

The dynamic analysis of the Yadanatheinkha bridge under construction without and with supporting of the king post are done by numerical analysis using OpenSees software due to El Centro 1940 earthquake to check the behavior of the structural members depending on the supporting of the king post. The earthquake motion are applied to the bridge in three directions simultaneously.

(5) Input earthquake motion for dynamic analysis

The El Centro 1940 earthquake is used for the dynamic analysis of the bridge under construction. Why the El Centro 1940 earthquake is used for the dynamic analysis is that El Centro earthquake record is the typical and famous among the earthquake engineering researchers for decades and another reason is the data difficulities for the region to amplify the actual earthquake data for the analysis. The earthquake record is long for 53sec and peak value of acceleration is 341.7gal in the N-S direction, 206.3gal in the vertical direction and 210.1gal in the E-W direction respectively. The earthquake time history is shown in **Fig. 16**.

(6) Results of dynamic analysis

In dynamic analysis of the bridge under construction without supporting of the king post, the tesile and compressive stresses of the critical members adjacent to the support of the cantilever truss are obtained from the numerical analysis and compared with the respective allowable stresses. All the tension members passed and some of the compression members at the bottom chord of the truss failed to resist the applied load and stresses exceeded the allowable limits. The displacement time history of the node at the top chord of the cantilever truss in three directions are obtained. The maximum displacement in vertical direction is downward 0.912m which has drift of 0.0104 exceeded the allowable limit of 1% drift and failed to resist the applied gravity and seismic load. The maximum longitudinal displacement is 0.110m and 0.213m in transverse direction and the displacement time history is shown in **Fig. 17**.

In dynamics analysis with supporting of the king post, the vertical displacement of the node point at the upper chord of the cantilever truss is 0.0916m downward and drift of 0.000019 quite smaller than the allowable 1% drift limit and the bridge structure can successfully withstand El Centro 1940 earthquake. The maximum displacement in longitudinal direction is 0.00641m and transverse direction is 0.03703cm. The time history displacement for three directions is shown in **Fig. 18**. When compare to the vertical displacement of the node, the displacement without supporting of the king post is about 10 times larger than that of supporting of the king post and in longitudinal direction is about 17 times and transverse direction is about 6 times larger than that of supporting of the king post. The results show that the assistance of the king post is one way of construction techniques to be sure the safe and reliable method.

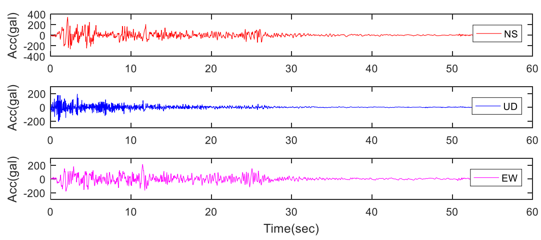


Fig. 16 El Centro 1940 earthquake record

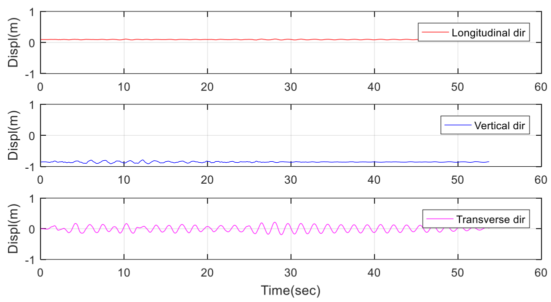


Fig 17 Displacement time history at the node in top chord of the cantilever truss without supporting of the king post due to El Centro 1940 earthquake

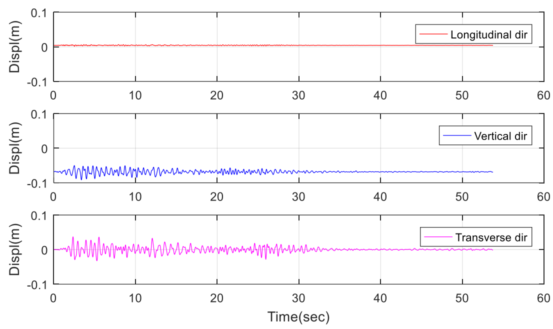


Fig 18 Displacement time history at the node in top chord of the cantilever truss withsupporting of the king post due to El Centro 1940 earthquake

From both static and dynamics analysis of the Yadanatheinkha bridge, it can be said that the support of the erection tower is important for the construction stage bridge structures to provide in the safe condition, to prevent from failure of the bridge and the supporting of the king post is one of the structural control technologies for the construction stage bridge structures.

5. CONCLUSIONS

Normally, the probability of severe earthquake during construction of the bridge is very low and seismic design for structures under construction is not important. The Yadanatheinkha bridge during construction collapsed due to the 11^{th} November 2012 Thabeikkyin earthquake in Myanmar. From the damage of the Yadanatheinkha bridge, 1.92million US$ lost. Lesson learnt from the Yadanatheinkha bridge collapse, it can be noticed that it is highly important to check the stability of the bridge under construction because of the dynamic loadings such as wind and earthquake. Even no earthquake during the construction period of the bridges, they may have many damages according to the histories of the bridge construction. Therefore, it is also important to check the stability of the bridge during the construction condition due to the gravity load effects in addition to the dynamic loadings. In construction of the bridge, without the additional support, it is not trustworthy to be sure the safe construction for the structure.

In this study, the static and dynamic analysis of the Yadanatheinkha bridge under construction is carried out with and without supporting of the king post to check the behavior of the structural members of the truss and to realize the important of the king post.

In static analysis of the bridge without supporting of the king post, all the tension members can withstand the applied loads and some of the compression members failed to support the structure. On the other hand, the bridge structure with supporting of the king post, all the tension and compression members can resist the load.

In dynamic analysis of the bridge without supporting of the king post, all the tension members can withstand the applied loads and some of the compression members failed to resist the applied laods. The vertical displacement of the node at the top of the cantilever truss exceeds the allowable limit. The bridge structure with supporting of the king post, the displacement of the upper node is within the allowable limit.

From the results of both static and dynamic analysis, it can clearly see that the supporting of the king post can reduce the damage of the bridge during construction not only due to the gravity load but also even under severe seismic load effect.

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