Experimental study to determine the oscillation of the base vehicle and cable tension during the TMM-3M bridge lowering process

Tran Duc Thang[1], Le Van Duong[1], Nguyen Duy Dat[1],
Dao Manh Quyen[2*], Chu Van Dat[1]

[1]Institute of Vehicle and Energy Engineering, Le Quy Don Technical University, 236 Hoang Quoc Viet, Nghia Do, Hanoi, Vietnam;
[2]University of Transport Technology, 54 Trieu Khuc, Thanh Liet, Hanoi, Vietnam.
[*]Corresponding author: quyendm@utt.edu.vn
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ABSTRACT

This paper presents the results of an experimental study on the dynamics of a TMM-3M heavy mechanized bridge vehicle during its lowering phase. A specialized measurement system was designed and deployed on the actual equipment to simultaneously record two key parameters: the vertical oscillation of the base vehicle and the tension of the drive cable. The experimental results show a high degree of agreement with previously established theoretical models. The findings reveal that the vertical displacement of the base vehicle's chassis has an average error of approximately 6% compared to the theoretical model. Additionally, the cable tension increases nearly linearly, with an average error of 6.4% throughout the entire lowering process. This study not only validates the accuracy of the dynamic models but also provides a scientific basis for assessing the structural safety and operational reliability of the equipment. The research results not only help validate the theoretical model but also provide a practical basis for assessing the operational safety of the equipment in terms of cable tension.

Keywords: TMM-3M; Military bridge; Experimental cable tension; Dynamics; Oscillation.

1. INTRODUCTION

In the modern era, the modernization of military equipment has become a priority strategy for many nations, particularly for military powers and developing countries with significant strategic positions. However, this modernization process is not without its challenges, most notably the substantial investment costs. Therefore, alongside the procurement of new systems, upgrading the technical capabilities of existing equipment within the armed forces is a crucial endeavor. The TMM-3M heavy mechanized bridge is a military bridging system produced by the Soviet Union since the 1960s, which remains in active service with the Vietnam Engineer Corps. This equipment has proven to be highly effective under Vietnamese operational conditions. Nevertheless, with the advancement of modern manufacturing technology, upgrading the TMM-3M bridging system is essential, aiming to reduce deployment and recovery times and minimize the number of personnel in the operating crew. After positioning the TMM-3M bridge at the deployment site, the launching process consists of four main sequential stages: frame lifting, span unfolding, span lowering, and intermediate support pier deployment. In practice, the TMM-3M's carrier vehicle is subjected to the simultaneous effects of the bridge span's weight, cable tension, hydraulic loads, and ground reaction forces. The oscillations generated during the span-lowering phase not only affect the vehicle's stability but can also cause sudden surges in cable tension, leading to risks of overload or localized damage. Consequently, an experimental investigation to determine the oscillatory characteristics of the carrier vehicle and the variation patterns of cable tension during this phase is both necessary and significant from scientific and practical standpoints.

Due to the specialized nature of the military domain, theoretical and experimental studies on the deployment process of military bridges in general, and the TMM-3M in particular, are scarce worldwide. The few studies on military bridges primarily focus on general overviews [1], 3D structural modeling, and strength verification through simulation methods [2, 3]. Theoretical research on the TMM-3M bridge is also limited. Study [4] addressed the dynamic model of the TMM-3M's working equipment during the span-lowering stage but only considered the cable as an elastic element with a stiffness coefficient, lacking a damping coefficient [4]. Other research has examined the load-bearing capacity of the TMM-3M bridge when traversed by tanks and armored vehicles [5]. In [6], the authors investigated the TMM-3M's deployment during the frame-lifting phase, incorporating a hydraulic drive mechanical model to analyze the dynamics of the lifting process. In [7], the authors also presented a theoretical study on the dynamics of the working equipment as well as the entire system during the span-lowering deployment. The influence of engine speed on the span-lowering time was also presented in [8, 9], where the authors demonstrated that increasing the engine speed reduces the lowering time but poses a higher safety risk at excessively high speeds of 1600 to 1800 rpm. The cable, suspension system, and the ground at the outrigger locations are treated as elastic components characterized by stiffness and viscous damping coefficients that influence the span-lowering process. The dynamics of the TMM-3M's working equipment during the span-unfolding stage were studied by authors in [10], where the driving torque from the engine was considered under two laws affecting the unfolding process. Furthermore, the dynamics during the intermediate support pier deployment stage were examined in [11].

To date, no experimental studies on the various stages of the TMM-3M bridge deployment process have been published. Experimental research is a critical component of the overall study of the TMM-3M deployment dynamics, as it provides a scientific basis for validating theoretical models and contributes to the objective of upgrading and modernizing the TMM-3M bridge set. This paper presents an experimental study to determine the oscillation patterns of the carrier vehicle's chassis and the cable tension during the span-lowering phase of the TMM-3M bridge deployment, with a particular focus on the tension in the cable that drives the span-unfolding process. The research results will serve as a basis for comparison with theoretical findings to assess the validity of the theoretical studies.

Starting from the above requirements, this paper focuses on designing and conducting an experimental system to directly record the oscillation of the base vehicle and the cable tension during the lowering process of a TMM-3M bridge span. The measurement system includes force sensors, displacement sensors, and specialized data acquisition equipment, allowing for the collection of high-accuracy dynamic signal series. Based on this, the paper analyzes the oscillation characteristics of the base vehicle, the variation in cable tension, compares them with previous theoretical results, and discusses their significance for ensuring the safety and reliability of the equipment. The research results can serve as a basis for improving dynamic models of mechanized bridges and providing recommendations for rational operating modes in practice.

2. THEORETICAL BACKGROUND

A flat multi-body model for the dynamic analysis of the TMM-3M bridging equipment during the lowering process was presented in [8]. In this study, a comprehensive model including the base vehicle and the operational equipment was considered, with their mechanical correlation fully accounted for (Figure 1). The components are designated as follows: 1 – Front axle; 2 – Chassis;

3 – Rear outriggers; 4 – Linkages; 5 – Lifting frame; 6 – Bridge span.

Accordingly, the research model consists of 5 degrees of freedom: q (m) – vertical displacement of the unsprung mass of the front axle; y (m) – vertical displacement of the center of mass of the chassis; φ (rad) – pitch angle of the chassis; ω (rad) – angular displacement of the span; ϕ (rad) – rotational angle of the cable drum. Besides the geometric symbols shown directly in Figure 1, the following additional symbols are used:

$$\begin{gathered} l_1 = G_2F; l_2 = G_2G_3; l_3 = G_2H; l_4 = NF; l_5 = FG_b; l_6 = FH, L = HN \\ \gamma_1 = \angle FG_2L; \gamma_2 = \angle G_3G_2L; \gamma_3 = \angle HG_2L; \gamma_5 = \angle NFG_b; \gamma_6 = \angle HFG_2 \end{gathered} \tag{1}$$

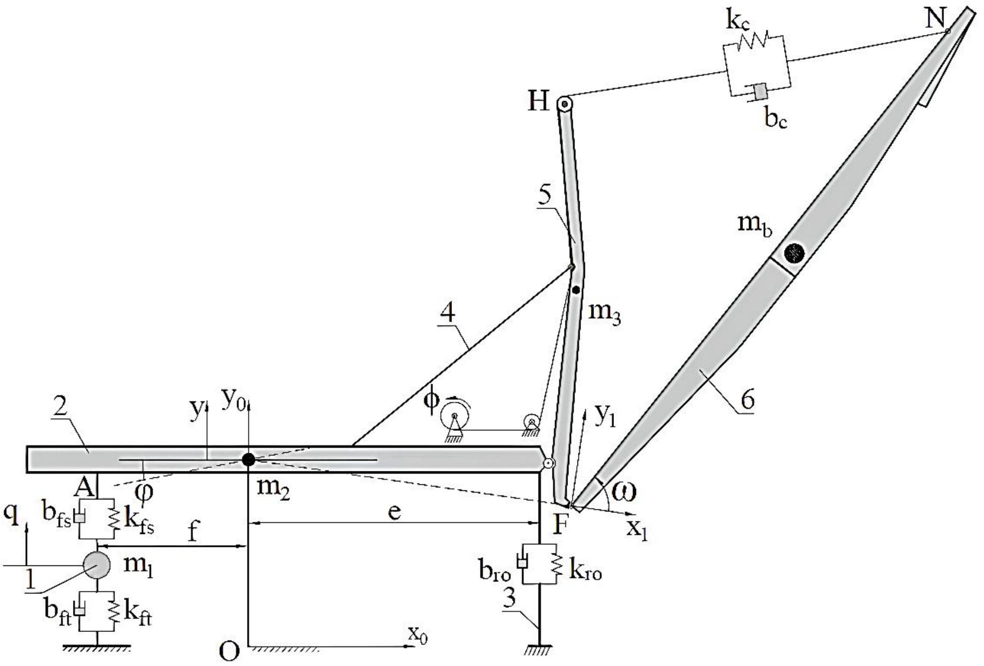


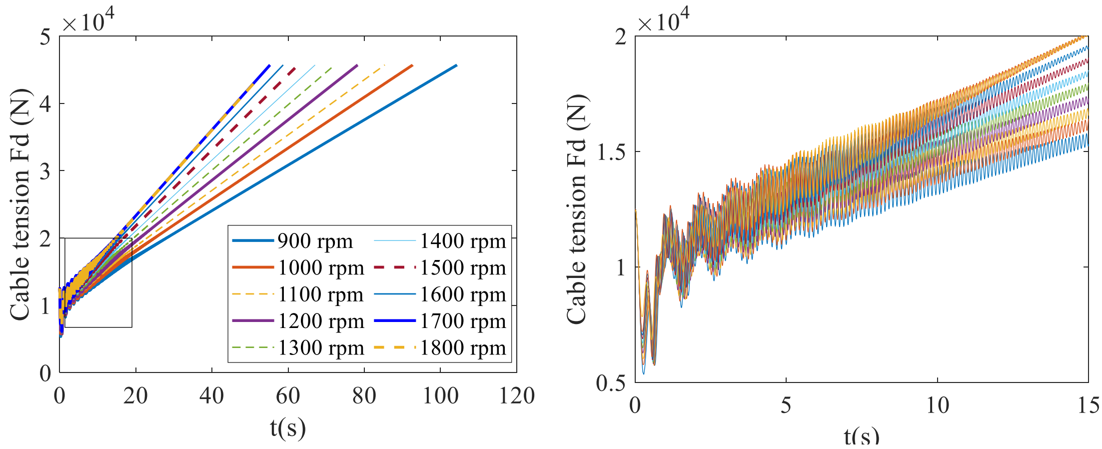
Figure 1. *Dynamic model of the TMM-3M bridge during the span lowering stage [8].*

The system of differential equations for oscillation, along with the input parameters of the mechanical system, was presented in [8]. According to this, the cable tension F_d (N) during the lowering process is determined by the expression:

$$F_c = \left\{ \begin{array}{l} \dfrac{m_b g l_5 L \cos(\varphi + \omega - \gamma_1 - \gamma_5)}{l_6 l_4 \sin(\omega + \gamma_6)} + k_c (L - L_0 - R_t \phi) \\ + b_c \left(\begin{array}{l} \dfrac{-l_4 l_6 \sin(\omega + \gamma_6)\dot{\omega}}{L} \left(1 + \dfrac{m_b g l_5}{k_c l_6 l_4} \dfrac{\cos(\varphi + \omega - \gamma_1 - \gamma_5)}{\sin(\omega + \gamma_6)} \right) \\ + \dfrac{m_b g l_5 L}{k_c l_6 l_4} \dfrac{\left\{ \begin{array}{c} -\sin(\varphi + \omega - \gamma_1 - \gamma_5)\sin(\omega + \gamma_6)\dot{\varphi} \\ -\dot{\omega}\cos(\varphi - \gamma_1 - \gamma_5 - \gamma_6)\dot{\omega} \end{array} \right\}}{\sin^2(\omega + \gamma_6)} - R_t \dot{\phi} \end{array} \right) \end{array} \right\} \tag{2}$$

The study in [8] showed the theoretical variation of cable tension corresponding to different engine speeds, as illustrated in Figure 2.

Accordingly, the cable tension tends to gradually increase in value as the bridge span is lowered and reaches its maximum value at the end of the lowering phase.



a) *b)*

Figure 2. *The dynamic tension force [8]:*
a) The original graph; b) Zoomed-in graph section.

3. EXPERIMENTAL SETUP

A dedicated experimental system was built and implemented on an actual TMM-3M bridging vehicle to determine the oscillation characteristics of the base vehicle and the variation in cable tension during the span-lowering process. The experiment's goal was to directly and accurately record key dynamic signals, including the vertical oscillation of the base vehicle and the cable tension, with a high degree of precision and reliability suitable for subsequent analysis. An experimental setup was designed to simultaneously measure two main groups of parameters: the vertical displacement of the base vehicle's chassis and cable tension. The vertical displacement of the chassis was recorded using a displacement sensor directly mounted on the frame, which measures oscillation relative to the ground. Meanwhile, cable tension was measured on the cable segment connected to the winch drum, utilizing an intermediate mechanism to convert the tensile force into a compressive force acting on a force sensor.

The system of measurement equipment included: an Omega LCMGD-120 kN load cell, installed on a nearly fixed cable section passing through two guide pulleys; two HF-750C displacement sensors, attached to the connection points of the front and rear suspension systems with the base vehicle's frame; and a Ni-6009 data acquisition unit, connected to a computer with DASYLab software to record the experimental results. Additionally, the experiment used signal amplifiers and specialized fixtures to convert the cable's tensile force into a compressive force on the sensor. The schematic diagram of the equipment connections is detailed in Figure 3.

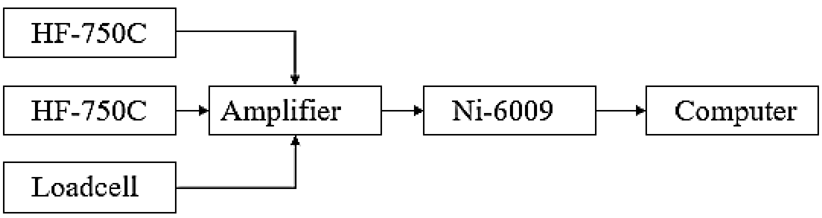


Figure 3. *Schematic diagram of experimental equipment connection.*

The cable tension was converted into a compressive force using a mechanical fixture. The electrical signals from the load cell and the HF-750 sensors were amplified and then transmitted to the Ni-6009 data acquisition unit. This unit was connected to a computer via DASYLab software, which saved all the measurement results. Figure 4 shows the actual setup of the experimental equipment on the TMM-3M mechanized bridge.

Figure 4. *On-site experimental setup for measuring cable tension:*
1- LCMGD sensor; 2- Ni-6009; 3- Computer; 4- Amplifier;
5- Fixture for converting tensile force to compressive force.

4. RESULTS AND DISCUSSION

Vertical displacement of the base vehicle's chassis was determined by converting the displacement measurements from the two HF-750 sensors. The motor operating speed during the experimental measurements was 1300 rpm (revolutions per minute). For the span lowering stage, the comparison between theoretical and experimental results for the vertical displacement of the base vehicle's chassis is shown in Figure 5. The graph in Figure 5 indicates a similar trend, where the displacement of the center of gravity gradually increases as the bridge span is lowered, which reduces the influence of the bridge span's weight on the base vehicle. However, in the initial phase, the theoretical displacement graph oscillates more intensely. During the first 15 seconds, the theoretical curve oscillates with an average amplitude of approximately 0.015 m around the static equilibrium position. After 20 seconds of lowering, the two curves converge and remain stable for the rest of the phase, with an average error of about 6%.

The error between the theoretical and experimental results is therefore within an acceptable range for a complex system with numerous nonlinear factors. Additionally, the theoretical oscillations show a larger amplitude than the experimental ones, meaning the model's predictions are on the safe side, ensuring that the structure is verified under more rigorous conditions than in reality. The similar trend in the stabilization of values between the theoretical and experimental results confirms that the model accurately reflects the physical nature of the system. Based on this, the study proceeds to investigate cable tension, one of the crucial factors determining safety during deployment.

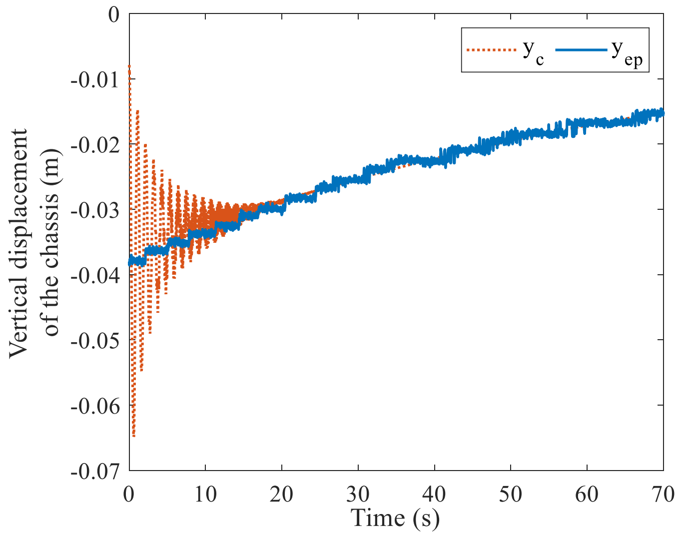


Figure 5. *The vertical displacement of the chassis.*

During the deployment of the TMM-3M heavy mechanized bridge, cable tension plays a crucial role as it directly impacts structural safety and reliable operation. Notably, the span unfolding and lowering phases are two periods with significant variations in cable tension, which also carry the risk of instability and cable breakage. The comparison between theoretical and experimental results for cable tension, shown in Figure 6, helps us identify dangerous states and evaluate the suitability of the theoretical model compared to the experimental data. A key point in the study of cable tension during the lowering phase is that the tension tends to gradually increase as the bridge span's center of gravity moves further away from the base vehicle.

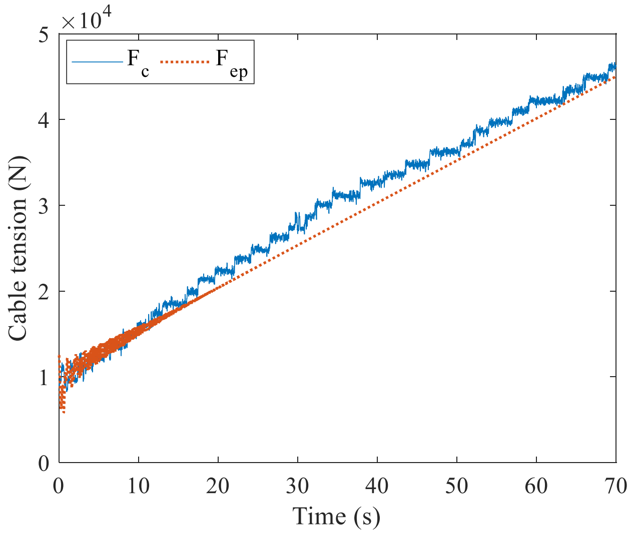


Figure 6. *Theoretical and experimental cable tension graph.*

The variation of cable tension shown in Figure 6 clearly demonstrates a similarity in trend. Both the theoretical curve F_c and the experimental curve F_{ep} show that the tension increases nearly linearly throughout the entire process, from approximately 10^4 N at the beginning to about 4.8×10^4 N at the 70th second. Starting from the 15th second, the theoretical curve appears smooth and steady, reflecting a stable increase in load. The error between the two curves during this phase is significantly smaller than during the deployment phase, with the largest error of about 12.9%

occurring at the 35th second. The average error throughout the entire process is 6.4%. The discrepancy between the theoretical and experimental results is less than 10%, which is considered acceptable for a mechanical system with multiple joints and links. This result indicates that the proposed theoretical model is appropriate and reliable, and it can therefore be used for further investigation of other related research problems.

5. CONCLUSIONS

The research and improvement of the TMM-3M bridge to enhance its technical and tactical capabilities, specifically, to reduce deployment and retrieval time and the number of crew members is a necessary trend of interest to military experts. Experimental research to determine the oscillation patterns of the base vehicle and the variation of cable tension plays a crucial role in validating theoretical findings and provides a scientific basis for future bridge improvements. This paper determined the base vehicle's chassis displacement and the changes in tension on the cable during the span lowering phase through a practical experimental study. The research results show a good agreement between theoretical and experimental findings regarding the displacement pattern of the chassis's center of gravity and the cable tension. This research is of significant importance for the comprehensive dynamic analysis of the TMM-3M bridge deployment process.

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TÓM TẮT

Nghiên cứu thực nghiệm xác định dao dộng của xe cơ sở và lực căng cáp trong quá trình hạ nhịp cầu TMM-3M

Bài báo này trình bày kết quả của một nghiên cứu thực nghiệm nhằm khảo sát động lực học của xe cầu cơ giới hạng nặng TMM-3M trong quá trình hạ nhịp. Một hệ thống đo lường chuyên dụng đã được thiết kế và triển khai trên thiết bị thực tế để ghi nhận đồng thời hai thông số quan trọng là dao động thẳng đứng của xe cơ sở và lực căng của cáp dẫn động. Kết quả thực nghiệm cho thấy sự phù hợp cao giữa dữ liệu thu thập được và mô hình nghiên cứu lý thuyết đã được xây dựng trước đó. Kết quả thực nghiệm cho thấy chuyển vị thẳng đứng của thân xe cơ sở có sai số trung bình khoảng 6% so với lý thuyết và lực căng cáp tăng gần như tuyến tính, sai số trung bình về lực căng cáp trong toàn bộ quá trình hạ nhịp là 6,4%. Kết quả nghiên cứu không chỉ giúp kiểm chứng mô hình lý thuyết mà còn cung cấp cơ sở thực tiễn để đánh giá độ an toàn trong quá trình vận hành của thiết bị về phương diện lực căng cáp.

Từ khoá: TMM-3M; Cầu quân sự; Lực căng cáp thực nghiệm; Động lực học; Dao động.