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The Innovative Structure Solution for Preventing Salt Intrusion and Retaining Freshwater In Mekong Delta VietNam

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ABSTRACT:

In the Mekong Delta Vietnam, the construction of sluices with the purpose of retaining fresh water and preventing salt water intrusion potentially plays a very important role. However, the structures constructed in small rivers according to local or traditional technology revealed many disadvantages related to the economical, evacuation and ecological conditions. Hence, the demand for large sluices in the larger rivers and estuaries is increasing.

In the Netherlands, several units of sluice caissons have been applied but their main function was only to permanently close the basin, while in Viet Nam only single caissons are applied as small river barriers. It is to be noted that a large discharge sluice with several caisson units has never been built so far in Vietnam or in the Netherlands. In contrast with this type of structure, most discharge sluices and barriers in the world have been built according to the “pier structure type”. In the Netherlands piers and bottom slabs are normally placed on batter pile foundations. In Viet Nam, piers are often placed on vertical pile foundations and a bottom slab is replaced by supporting beams.

Both “proven structure”- caissons and piers have their own strong and weak points; by combining the best features of “proven sluice technologies” of the Netherlands and Viet Nam, appropriate structure types were designed and the most critical concerns related to them were checked. Besides, the improvements and combination of the hydraulic automatic gates and caisson sluice are also considered. The final results show that they are feasible and innovative solutions for the sluices in the large estuary branches in the Mekong Delta Vietnam, which can be applied to discharge a large amount of water, prevent tidal penetration and retain fresh water.

KEY WORDS: Sluice, pier, caisson, hydraulic automatic gates, salt intrusion.

1 INTRODUCTION

The Mekong Delta region is one of the most important regions of Vietnam. It produces about 45 percent of Vietnam’s agricultural products. Millions of small farmers, thousands of private businesses, over 700 state owned enterprises, and several cooperatives contribute to the vibrant economy of the Mekong Delta. Known as the country’s rice bowl, the Mekong Delta produces about half of the rice consumed in Vietnam and 80 percent of Vietnam rice exports. However, this area now is suffering from many issues. The relative low elevation of this area in combination with the increasing extraction of drinking water and the flooding problem from the effect of sea level rise as well as salt intrusion are now of primary concern for these areas. The low-lying land area is located near the mouth of the large branches of the Dong Nai and Vam Co River system and therefore it is strongly affected by the variation of the flow in the river and, an even more dominant factor, the tidal current. Large reservoirs have been built upstream retaining the flood flow, leading to a decrease in the amount of average flood flow. Conversely the effect of the tidal current is increasingly higher, resulting in salt intrusion and lack of fresh water. The overall impact is that more areas are suffering from tidal flooding. Moreover, the effect of the sea level will add to these impacts and make it more severe.

With the aim of solving the tidal flooding and salt intrusion, the Vietnamese Ministry of Agriculture and Rural Development has submitted many proposal plans to construct discharge sluices (more than 100 small , medium and large sluices) in the river to prevent salt intrusion and keep fresh water. However, many projects have been delayed until now due to funding constraints and/or site clearance issues in the surrounding areas. They are costly and time consuming; moreover, their efficiency in flooding protection is still being questioned. That is an important reason why the interest in larger sluice structures in deep rivers and estuaries is increasing in Viet Nam. A larger discharge sluice in deeper and larger estuaries will provide a higher level of protection against flooding and saltwater intrusion. The technology of constructing sluices or river barriers in small rivers with a low hydraulic head and water depth in order to prevent flooding and saltwater intrusion has been done in Viet Nam; nevertheless, the construction of large sluices in the larger and deeper estuaries is a new development and a large challenge.

The traditional sluice structure and its related construction method have advantages of easy to check and verify the quality during the design and construction period, however, this kind of traditional technology in construction sluices has two main disadvantages, i.e. (1) the extreme large volume of work and (2) the extreme high cost compared to the scale of project. The main reason for the high cost is due to the difficulties in ground clearance as well as construction due to crowed population, land use problem as well as the foundation issues which is extreme weak and sensitive to external forces. Besides, during high tide, the demand for freshwater at downstream of structure is difficult to achieve.

The lack of experience and insights in building such large structures as in the Netherlands put more pressure on local researchers in Viet Nam in finding appropriate structures that can be applied in large and deep estuary in limited conditions of Viet Nam which will be one of the most affected countries by the climate change phenomenon, especially due to the sea level rise effect.

By studying “proven sluice structures” in the world and combining the best features of them with that of Vietnamese sluice structures, while checking the critical problems related to them and then improving the negative features, innovative sluice solutions could be achieved that are proven to be feasible solutions for the discharge sluice at large estuaries in developing countries.

2 STUDY METHODS

A literature review on different types of structure allowing water flow over, especially discharge sluice systems and large barriers in the world was conducted, in context of structure type, construction method and operational mode. These “proven structures”, particular in the Netherlands and in Viet Nam provided the understanding of different types of structure have been successful constructed up to now that can be applied for the discharge sluice structure.

The main types of structure, especially with a focus on its structure elements was analysed and studied. The best features of “proven structures” that are suitable for the construction in developing countries was figured out. Besides, the advanced technologies related to the construction as well as a structural solution of the discharge sluice was also considered. The innovative structure was achieved by combining all the best possible features .The applicability of them was proved through checking the most critical problems (stability, seepage, foundation and so on.) related to its capacity to fulfil its representative functions.

3 RESULTS AND DISCUSSION

3.1 Operational principle

It can be seen that all discharge sluices (Haringvliet, Afsluitdijk sluice system, and Saemangeum sluice) are operated with the same principles: The discharge sluice will be closed when the water level at the sea side larger than that at the basin (negative hydraulic head). The discharge sluice will be opened only when the water level of the basin exceeds that at the sea side (positive hydraulic head). A certain value of the water level inside or outside can also be considered as a reason to close or open the discharge sluice. It means that the discharge sluice will be closed until the time that water level at the basin reaches a given maximum value (maximum allowable storage level). The water level of the basin will oscillate with the tidal fluctuation. When the water level of the basin exceeds that at sea side, the discharge sluice is opened leading to a decrease in the water level of the basin. This reduction will continue until the time when the water level of the basin equals that at the sea side and the discharge sluice will be closed. Then there is no water being discharged through the sluice while water from the river still flows into the basin. The result is an increase in the water level of the basin. The water level of the basin will continue to increase until the time when the water level at the sea side is exceeded; the discharge sluice will be opened again at this time resulting in a decrease in the water level of the basin. Since tides in the study area have a semidiurnal characteristic, this operation is expected to be repeated two times a day. It can be seen that there is no inflow (water flowing from the sea into the basin), only outflow (water flow from basin into the sea) which will eventually result in a basin with fresh water. (Figure 1)

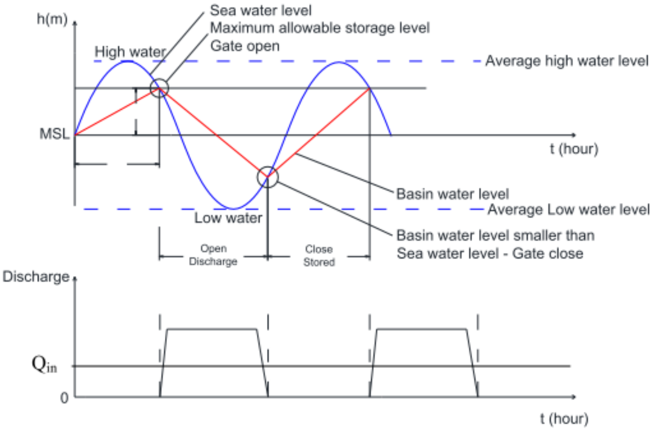

Figure 1 Operational principle of discharge sluice structure in order to prevent salt intrusion and keep freshwater

3.2 Structure Type Principle Analysis

The technology of design and construction sluice structure is a typical part of the Dutch civil engineering industry with a rich history and various famous structures. Large scale projects of discharge sluices such as Haringvliet, Afsluitdijk sluices system or Oosterschelde storm surge barrier (largest barrier structure of the world) now are a part of history and a symbol of this country. These projects consist of various types of sluice structures including a variety of types of gate, piers and foundation treatment as well as their various construction methods .The success in the operation and the stability of these projects proved the correctness of their structure in large scale project .

After studying and reviewing several structure types of discharge sluice and storm surge barriers, it can be stated that there are two main possible options for the structure type of discharge sluice in, one using large pier system (Haringvliet, Saemangeum and Oosterschelde) and one using prefabricated caissons (used to permanently close the basin such as in Brouwersdam)

Caisson structure due to its advantages (simple in construction, flexibility) is a type of prefabricated structure used with various purposes. It can be used for breakwaters, quays or even for foundation treatment purposes. The caissons are usually prefabricated in a building dock and then towed to the construction site where it will be immersed by filling with materials. Nevertheless a caisson sluice structure in the Netherland was only used to permanently close the basin and it has never been used for discharge water function purpose before. While in Viet Nam it is only applied as sluices in very small rivers and hydraulic head (1-2 m) with only a single caisson unit. Then the caisson structure type according to the “proven structure” of caisson in the Netherlands with several units was considered.

Although similar in the structure type, “Pier structure” itself can be applied in many ways. For the piers in Haringvliet sluice, the stability of the whole structure based on the deep foundation (pile foundation), the piers system and bottom slabs are the main parts take response for the loadings (vertical and horizontal) and transmit them to the batter piles below. Pier structure in Oosterschelde storm surge barrier on the other side operated in a different way, although it is also the main part bearing loadings, its stability mainly based on the friction. Between structure and subsoil due to its great mass (shallow foundation). Piers in Oosterschelde are a separated system. Two supporting beams are used instead of a bottom slab which can reduce a significant volume of concrete required. (Figure 2)

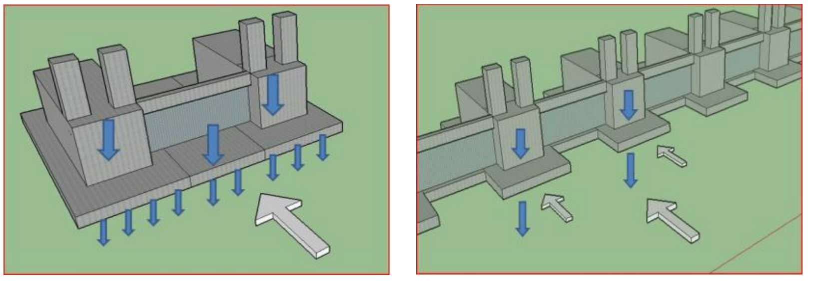

Figure 2 Loading transmitted principle of different type of pier structures

In Viet Nam pier sluice structures applied are similar with that in Oosterschelde storm surge barrier; however, its stability is based on deep pile system. The main concerns is that pier structure in Viet Nam was just only applied for the small hydraulic head (1m), besides the pile support system is only consists of vertical piles which is relative weak to resist against horizontal forces from hydraulic head (Figure 3). From the above analysis the ideal of applying pier structure sluice as a separated system placed on batter pile foundation, with two supporting beams instead of a bottom slab was studied.

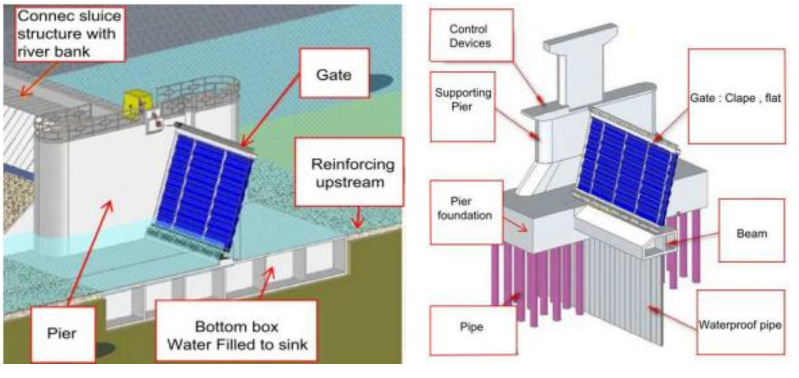

Figure 3 Caissons and Pier sluice structure applied in Vietnam

Both “proven structure”- caissons and piers have their own strong and weak points; by combining the best features of “proven sluice technologies” of the Netherlands and Viet Nam, appropriate innovative structure types were achieved which are (figures 4):

- The pier sluice structure in which supporting beams are used instead of a bottom slab, and their main stability base on batter pile foundation
- The caisson sluice structure containing several units

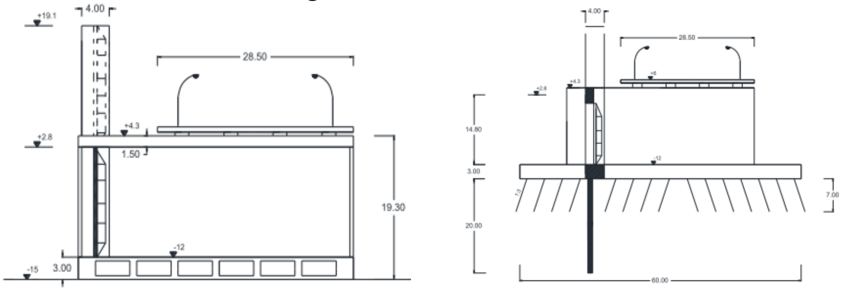

Figure 4 Cross - section of caisson sluice structure and pier structure with combined positive features

3.3 The applicability checking

The applicability of pier and caisson sluices will be proven by checking the critical problems related to its capacity to fulfil its representative function in the first design (Table 1). The possible alternative solutions also need to be studied to improve and enable structure to overcome the critical problems. The data used for calculation checking (waves, foundation, topography…) was obtained from the Vung Tau - Go Cong, where a project of a large discharge sluice is being studied.

Table 1 Critical issues checking

Most critical problems checking	Meet the requirement	Feasible solution	Accepted
Overtopping	✓		✓
Maximum draught	x	✓	✓
Statically stable	✓		✓
Dynamic stable	✓		✓
Strength of wall and bottom plate	x	✓	✓
Sliding	✓		✓
Rotational stability	✓		✓
bearing capacity (strength) of foundation	✓		✓
settlement (stiffness) of foundation	✓		✓
Piping	✓		✓
Stiffness structure and subsoil reaction	✓		✓
resulting forces and the bearing capacity of the piles	✓		✓
Batter Piles and Piles distribution	✓		✓
Connection	✓		✓
Scouring	x	✓	✓

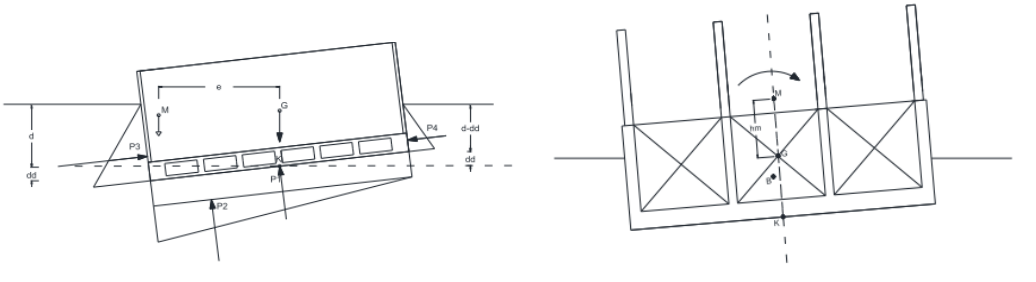

Figure 5 Example of Checking unequal draught due to asymmetrical distribution of weight and Floating element stability Checking

The most critical problems of the caisson structure type focus on the possibility of floating them to the construction site and its stability during the operation (example in Figure 5). These problems were checked in order to ensure that all the problems can be overcome. For pier structure, a more general type, the main concern are now only focuses on "the new feature" of these type of structure which are the combination of supporting beam and batter pile foundation.

From the checking results the main draw conclusions are: All the most critical problems related to the capacity of fulfilling the functions of caisson and pier sluice structure can be overcome. The possibility of transporting caissons, the stability of caissons during transporting stage and during the operational stage can be ensured. For pier sluice structure, by using supporting beams instead of the whole bottom plate and using batter piles instead of vertical piles and, the required number of pile will be significantly reduced (for the batter piles with 1:3 slope, the number of piles require reduced about 2.5 times) while the stability of the sluice structure is still ensured.

3.4 The application of Hydraulic automatic gate

Hydraulic automatic gate was named "automatic door gate" since its shape look similar with the door. It operates based on the principle of the deviation between the top and bottom swivel joint along the axis of revolution situated on the edge of the gate.

3.4.1. The operation of Hydraulic automatic gate

"Hydraulic automatic door gate" operated mainly based on three main forces which are the water pressure upstream and downstream, weight of the gate and the "axis deviation force". Axis deviation force is arisen from the deviation between the top and bottom swivel joint along the axis of revolution. This force play an important role in the operation of the gate, enable the gate to automatic close when the water pressure upstream equal that downstream. The combination of the deviation force, the weight of the gate and the water pressures difference between upstream and downstream allow the gate automatically close or open. The upper and lower swivel joint is placed deviated θ^0 in the plane of gate with the purpose of arising axis deviation force. (Figure 6)

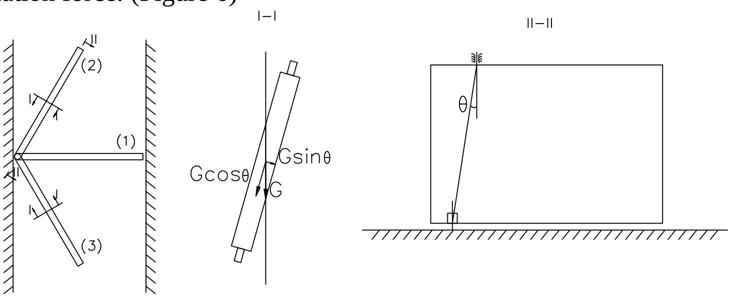

Figure 6 Scheme of Hydraulic automatic door gate

Normally, when the gates close, the axis deviation force equals zero. The gates will automatically open when there is certain water pressures difference between upstream and downstream. Due to axis deviation, the gate will be inclined θ^0 degrees.

Experiments show that with the appearance of waves, the gate still can be closed automatically; however it will require more time to close (one-third of total time). Therefore, in practical design, the wave force is usually neglected. Experiments show that with $\theta = 3^0$, the necessary value of the difference between water level upstream and water level downstream is only 2 cm for the automatically opening of the gate. Usually, θ is usually chosen 3^0 for the gate with 8m width and 6 m height.

3.4.2. The combination of Caisson and Hydraulic automatic gates

The main principles for the application between caisson sluice structure and hydraulic automatic gates are illustrated in Figure 7 and 8.

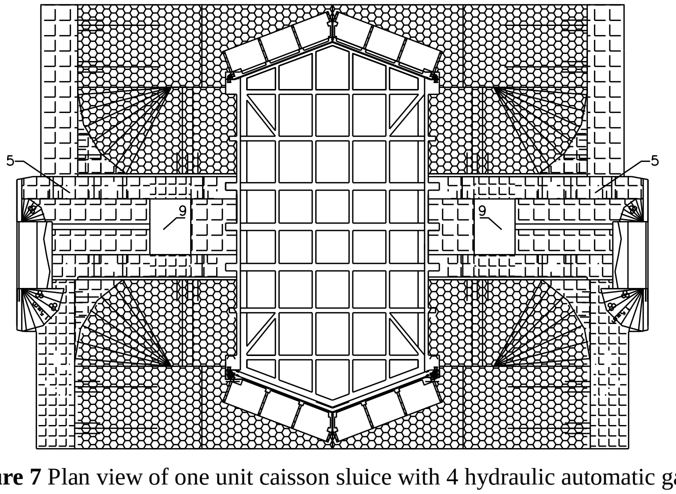

Figure 7 Plan view of one unit caisson sluice with 4 hydraulic automatic gates

The body of the structure including the bottom slab, upstream and downstream gates and two outer walls will create an empty box which enables the structure to be floated and immersed. These components will take responsable for the loadings (vertical and horizontal forces) and will transmit them to the foundation. All beams and slabs are connected in order to achieve the necessary stiffness. The stability of structure against the sliding, overturning, piping, scouring and the stability of the foundation were checked. The calculated results show that the entire requirements are met.

The operation of caisson sluice which have the hydraulic automatic gates can be seen in figure 8. In dry season, the main functions of structure are fresh water keeping and salt intrusion prevention. Therefore the upstream and downstream gates will be placed in free state, position A. In this position, the upstream gates keep fresh water easily while the downstream gates automatic prevent salt intrusion easily.

In rainy season, the main objectives of the structure are tidal prevention and flood discharge. Thus, the upstream gates will be anchored in position B in order to free discharge water. The downstream gates will be placed in position A to automatic prevent tide and flood discharge**.** If there is a demand for fresh water during high tide, the upstream gates will be placed in position A to automatically get fresh water while the downstream gates will be anchored in position B to get fresh water. When the salinity of water downstream reach required level, the gates will be pull into A position to preventing salt intrusion.

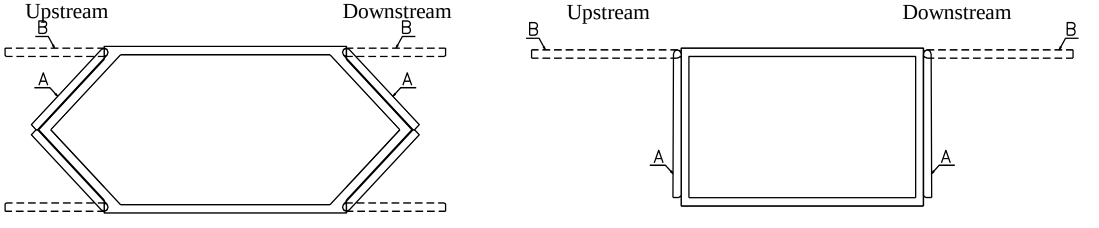

Figure 8 The operational principle of caisson sluice with 4 hydraulic automatic gates (a) , 2 gates (b)

4 CONCLUSIONS

In Viet Nam the interest for the construction of such a large sluice structure as Haringvliet of the Netherland is increasing. Most sluices in Viet Nam only have been built in shallow rivers with small hydraulic head. It is also difficult to apply exactly the technologies of developed countries in a developing country like Viet Nam. The main purpose of this paper therefore is to study and present the appropriate structure solution for a large discharge sluice in Vietnam. Firstly, in order to gain the insight into the general types of sluice structure, proved structures (successful constructed structures) over the world was studied. The answer to the research question is expected to be found in the light of the past, by studying similar successful constructed structures, analysis and chosing the best “feasible structure types” to apply in the study area. After reviewing various structure types in the world, including discharge sluice and barriers, it can be concluded that most of the discharge and barrier structures can be categorized into two main types: “Caisson” and “Pier”. Caisson is a type of structure that will be prefabricated in dock and then be transported to the construction site where they will be immersed with material. In the Netherlands, several caisson units of have been applied but their main function is only to permanently close the basin, while in Viet Nam only a single unit of caisson is applied as small river barriers. It is to say that a large discharge sluice with several units of caisson has never been built so far. In contrast with this type of caisson sluice, most of discharge sluices and barriers the world over have been build according to the “pier structure type”. Piers placed in shallow foundation are more costly than piers placed in deep foundation and therefore are not considered as a feasible solution for a developing country. In the Netherlands, pier structure usually consists of a system of large piers which are connected with a bottom plate and together placed on batter piles foundation. In Viet Nam, a bottom slab is replaced by a supporting beam; however, the piers are only placed on vertical piles which are relative weak against the horizontal forces from the water pressure. Because both “proven structures”- caisson and pier based and applied in Vietnam and in the Netherlands have their own strong and weak points, it can be expected that by choosing and combining the best characteristics of these proven technologies, the new combinations will provide significant improvements to current sluice structure type resulting in solutions to problem being addressed. In other words, appropriate types of discharge sluice structure are expected to be achieved by combining the best features of these “proven structures”, particularly in the Netherlands and in Viet Nam. That is the reason why the caisson structure type which was only used to permanently close the basin in the Netherland and pier structure type with supporting beams placed on batter pile system were chosen as structure solutions for further considerations in the first design. Based on the data collected and the requirements of the discharge sluice as well as with the support of rule of thumbs, basic dimensions of structures were estimated, after that the most critical concerns related to the chosen structure types was checked and the final conclusion is drawn is that they are innovative and feasible solution for sluice structure in developing countries. Besides, the combination of caisson sluice structure with Hydraulic automatic door gate was also studied. It can be seen that although the application of caisson sluice and pier sluice structure instead of traditional sluice technology brings lots of benefits, it still cannot complete solve the problem of preventing salt intrusion during the high tide. The improvements and combination of the hydraulic automatic gates and caisson sluice will provide a complete solution to overcome this problem.

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