Inflatable Weirs: A Viable Alternative for Bandhra/ Barrage Structures

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Abstract: In India where many rivers run dry after the end of monsoon, it is a need of the day to store block the post monsoon flows for drinking and irrigation etc. In order to save and optimally utilize water for drinking and irrigation needs. Ministry of Road Transport and Highways (MoRTH), Govt. of India, New Delhi has decided vide its letter dated 18 April 2017 that the bridge sites for all new bridge structures and old abandoned bridge structures having total length 100 m or less can be used for storing water for drinking and other purposes by constructing *bandhara*/barrage structures. The paper discusses in brief about the *bandhara*/barrage structure, constructed and planned in the country, the basic design elements and analysis and design with inflatable weirs instead of conventional gates. The paper emphasizes that inflatable weirs be considered as one of the viable alternative for constructing bandhara/barrage structures for conserving water in the post monsoon period.

Keywords: *Bandhara/*Barrage, Floods, Disasters, Water Conservation, Rubber Dam, Water Scarcity

1.0 Introduction

In our country, where many rivers run dry after the end of monsoon, it is a need of the day to store the post monsoon flow for drinking, irrigation, etc. Scarcity of water can be understood from the facts that for the first time in the country Section 144 was enforced in the Latur City of Maharashtra to avoid water conflicts and the first Jaldoot Special Train was operated for four summer months by Indian Railways from 11th April 2016 to transport the water from Miraj in Osmanabad to Latur covering a distance of 343 km. Initially, the first 'Jaldoot' carried 10 tanker wagons each carrying 50,000 litres water and later, the number of wagons were increased to 50 to carry 2.5 millions of water and it supplied nearly 240 million litres water through 111 trips to Latur and some adjoining areas.

In Barmer district, Rajasthan, water has become severely scarce and often water gets stolen, as a result, the residents have resorted to extreme measures such as using locks on the barrels in their backyards to avoid water theft.

In 2019, Chennai was in news due to an acute water crisis during summer months and the southern metropolis faces a daily water deficit of at least 200 million litres. A train with 50 tank wagons, carrying 50,000 litres of water each, total 2.5 million litres of water transported from Vellore to Chennai, beginning from July 12, 2019 and around 100 inlet pipes installed near the railway tracks were installed to discharge 2.5 million litres of water to a treatment plant after passing through a conduit, which has been grappling with an acute water crisis over the past few months.

Ministry of Road Transport and Highways (MoRTH), Govt. of India, New Delhi has also decided vide its letter dated 18 April 2017 that henceforth, the bridge sites for all new bridge structures and old abandoned bridge structures can be used for tapping of water for water conservation for improving recharge of ground water and availability for drinking water supply, etc. by constructing *Bandhara*/Barrages/Weirs. The Ministry of Jal Shakti, Govt. of India has already begun water conservation in 255 districts in the Country to provide water to the people.

In order to conserve water, the *bandhara*/barrage type structure may also be constructed on downstream side of bridge structure to store the water upstream. In this type of structure, barrage is designed as secondary structure in the downstream of bridge with piers and height of the gates limiting to 3.5m or so to store water in the last phase of monsoon. The pond level of the *Bandhara*'s is fixed to harness the maximum storage with no submergence and land acquisition. The water stored within the river banks will not require additional land acquisition and hence the scheme can be popular. The main purpose of constructing such *bandhara*/barrage type structure can be defined as:

1.1 Water Harvesting Structure

The primary aim of *bandhara*/barrage type structure is to store the after monsoon flow of water and to use is for long time. This requires some special site conditions such as availability of nonporous rock/soil, impervious banks. The water is stored when there is availability of water and it is utilised according to the need of people particularly in the most arid months of March to May.

1.2 Artificial Recharge Structure

Where pervious soil/sandy soil/fissured rock is available at site, the water harvesting structure can be used for artificial ground water recharge. It will contribute to raise the ground water availability of entire area in the vicinity, which can ultimately be utilised by the society in vicinity.

Number of *bandhar*a/barrage structures has already been constructed in the country and Govt. of Maharashtra has already taken a step to construct such type of structures and some standard designs are also available for constructing *bandhara*/barrage structures (Ingle 2016).

2.0 Bandhara/Barrage Structures

In India, we have rains only for 3-4 months and then it is dry weather, so water is needed during lean period. The concept of building low height dam all along the river was introduced in the Maharashtra on the downstream of bridges to store water after rainy season is over so that the storage can be used for agriculture purpose as well for drinking. The technique of constructing a special type of weir across the river bed to store the water in post – monsoon season, was first implemented in Kolhapur, Maharashtra back in the era of Rajarshi Shahu Maharaj for meeting the agricultural water demand once monsoon surpasses. KT weir (Kolhapur Type *Bandhar*a) is a structure to be constructed transverse to the flow of natural stream channel having considerable gap between two piers to allow the passage to water stream. These gaps being sealed with needle gates to restrict the flow of water so as to store it for future use when channel is having water deficit and do not have enough water to serve the human needs. This creates a storage reservoir at the upstream side of the structure which is being majorly used for fulfilling various water demands. Particularly, it is a non over flowing weir with a concrete deck at top which can be used as a bridge for light to medium traffic.

The KT weir gates are put in operations at the end of tropical monsoon since considerable amount of water can be stored. These gates are either manually operated or mostly operated with hoisting equipment. Since the ages, the gates were conventionally made from mild steel and reinforced with bracing to provide the strength. In modern day practice, the conventional material is replaced with the Fiber Reinforced Plastic (FRP) needle gates to achieve the efficiency in operations.

The *KT Weirs*, which were constructed in large numbers, have remained in a state of neglect for 15 years. The *Bandhara* weir is a typical gravity structure and can be constructed at any suitable location or along any bridge structure. Now-a-days, more than 100 *bandhara/*barrage structures are under construction and planning stage in the state of Maharashtra.

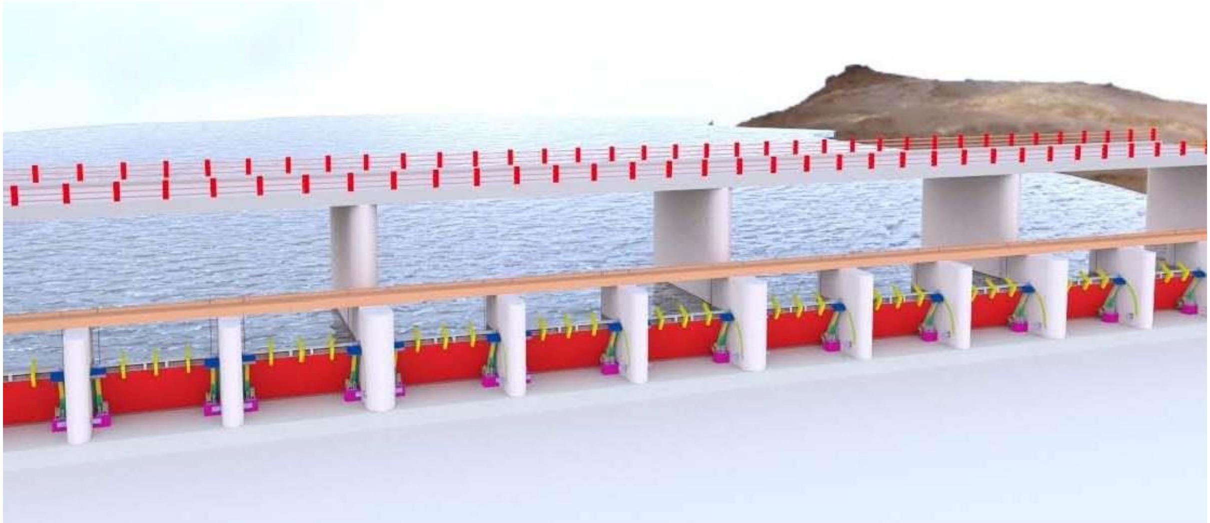


Fig.1 –Typical Bandhara/Barrage type structure (MoRTH, 2017)

Fig.2 –*Bandhara*/Barrage Structure constructed on Addan River, Distt. Yawatmal, Maharashtra (MoRTH, 2017)

2.1 Design Philosophy

In *Bandhara*/Barrage Structure (Bongirwar 2003), the water way is divided in to number of small spans, ranging from 2m to 3m and the water is stored up to a total height of 3.5m, depending upon the discharge in the river in the lean season to be used for various purposes. Many times, overflow weir is also provided on one bank or both banks to pass the sudden flow of water because it may harm the structure. Upstream and downstream protection works are also provided to safeguard the structure. The 2m x 0.50m gate panels are used to create the water storage. The weight of each panel may vary from 50 to 100 kg, depending upon the span and height of panel. The main components of these structures include (a) gates with emergency manual hoisting arrangement, (b) barrage including energy dissipation arrangement, fish ladder, piers and abutment with guide wall (c) afflux bund and bank protection works, and (d) Other ancillary works.

2.2 Design Loads

Generally the following loads are considered in design the barrage structure:

- Dead load
- Static weight of water when gates are closed
- Moving water at highest flood level (HFL) without gates
- Earth pressures
- Buoyancy is considered when water is at HFL and no gates
- Earthquake forces when water depth is 50% of total depth.

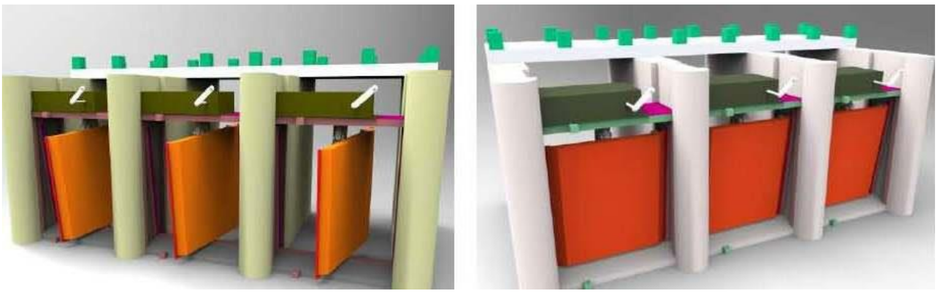
2.3 Gates

In olden days these barge/needles/gates/barriers were made from wooden planks, which were inserted in the grooves and soil/mud was pressed between the gaps at the end of rainy season period or on lean period to prevent water flowing to downstream. Different type of light and strong materials are now available, which can with stand the small water pressures, as these gates are installed in the last phase of monsoon and removed much before onset of monsoon to avoid damage to main structure. Study of rainfall pattern is carried out to decide time for placing of gates. For different types of gates, used in the construction of *bandhara*/barrage structure are shown in Fig. 3.

Steel Gate

Fibre Reinforced Plastic(FRP) Gate

Fibre Concrete Gate

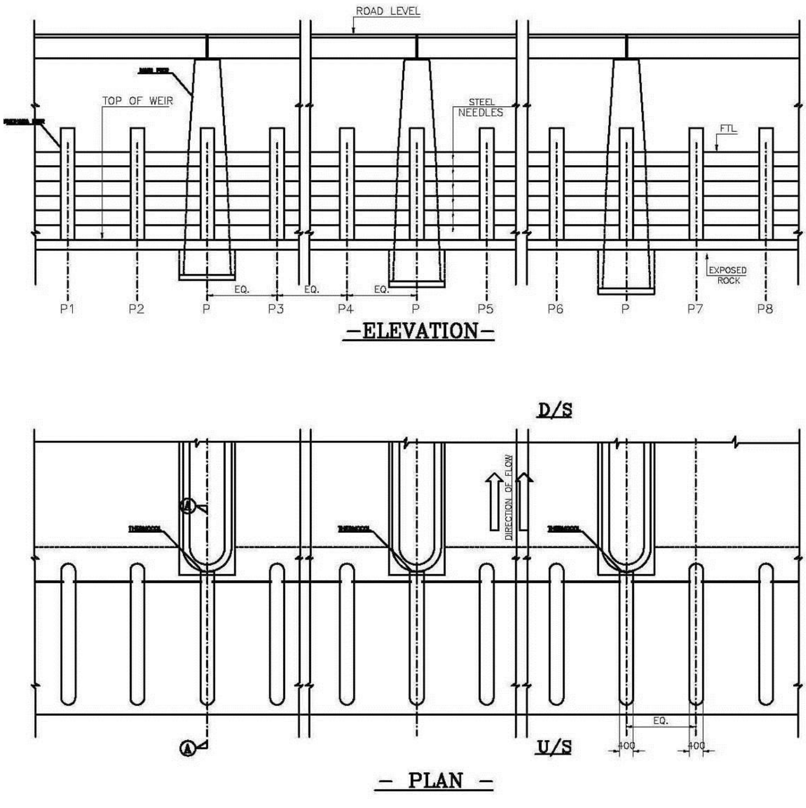


Godbole Gate in Open and Closed Condition

Fig. 3 –Gates Provided in *Bandhara*/Barrage Structure (Ingle, 2016)

Mechanical simple equipment or movable Cranes shall be needed to expedite fixing and removal operations of the gates. However, Godbole gates does not require any such arrangement.

These structures, are designed as per Indian Road Congress (IRC): 6 and other Indian Standard (IS) Codes and stability of structure is checked against overturning, sliding, uplift and for maximum and minimum pressures at the base. Typical details of *bandhara*/barrage structure are shown in Fig. 4.



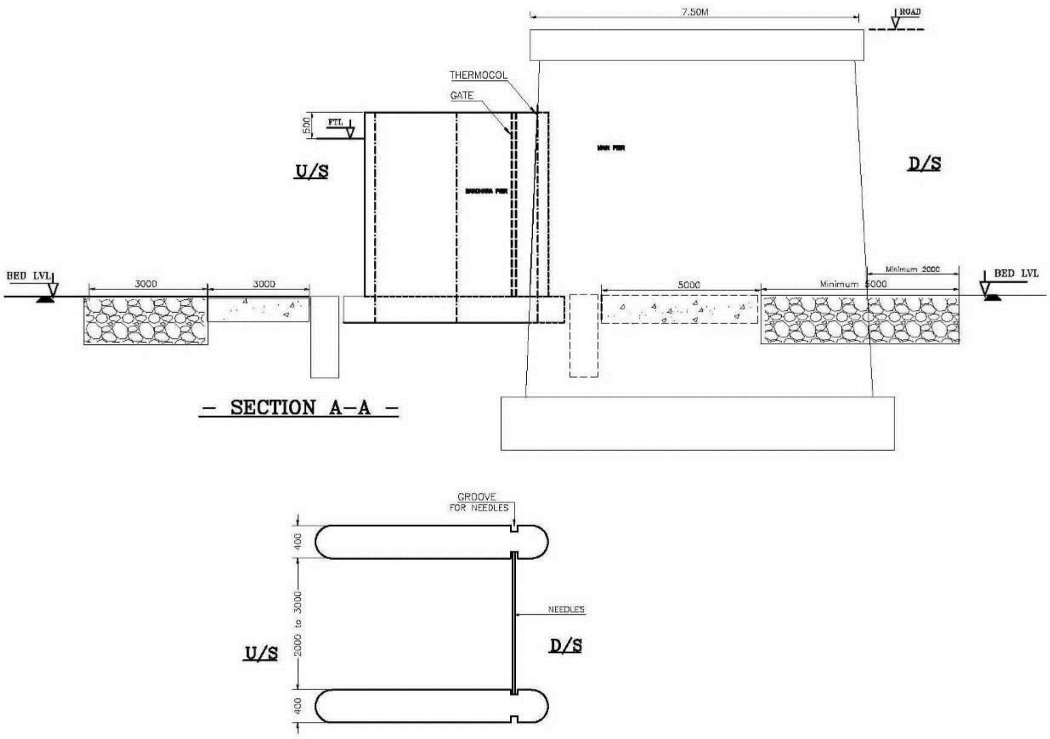


Fig. 4 –Typical Arrangement of *Bandhara*/Barrage Structure (Ingle, 2016)

3.0 Inflatable Weirs

The main disadvantage of *Bandhara/*Barrage Structure is that raising and lowering of shutters/gates on the barrage crest is not convenient and requires considerable time and labour, long construction time and high maintenance cost. Inflatable dam is a type of gate for storage diversion structure to control and regulate the water for conservation. The ease of inflation and deflation allows the rubber dam to be routinely cleaned from deposited silt as well as safe against the flood. In the recent past inflatable dams have been increasingly accepted and are widely used worldwide.

Inflatable weirs, also known as rubber dams are flexible elliptical structures made of rubberized material attached to a rigid concrete base and inflated by air, water, or a combination of air/water. When they are inflated they serve as weir and when they are deflated they function as a flood mitigation device and provide automatic flushing of sediments. The simplicity and flexibility of the rubber dam structure and its proven reliability are key consideration in its wide scope of applications. The first inflatable dam was developed in mid-1950s by an American engineer, Norman Imbertson. It was 1.52m high, 39.6m long and was inflated by a combination of water and air. India’s first rubber dam was built in 2005 on Janjhavati River, which was completed in six months.

3.1 Global Experience of Inflatable Dams

Anwar (1967) investigated experimentally small overflow of rubber dam and when fully-inflated rubber dam, the downstream face of the dam follows closely the shape of circular cylinder. Binnie (1973) in his theory of flexible dams inflated by water pressure derived relations between the internal pressure and the height, the length of the curved perimeter of the dam and the base width. Theoretical calculation of the shape of these dams was carried by

Watson (1985). Hsieh and Plaut(1990) considered Two-dimensional linear vibrations of inflatable dams. Ishimura (1995) described a method to protect the rubberized fabric from impact of boulders by placing a cushion inside the tube which, when deflated, helps absorb the impact. Wu and Plaut (1996) analyzed the vibrations of inflatable dams and investigated the dynamic behavior of an inflatable dam subjected to overflow. Choura (1997) considered the suppression of structural vibrations in air-inflated membrane dam by its internal pressure.

Tam (1997, 1998a, 1998b) studied use of rubber dam for flood mitigation in Hong Kong. Chanson (1997, 1998) reviewed the overflow of inflatable flexible membrane dams (IFMD) and detailed both deflated and fully-inflated configurations. Zhang et al (2002) provided a detailed discussion on various issues related to the construction, operation, maintenance, and repair of the 20 rubber dams that have been installed in Hong Kong. The behavior of air or water inflated dams under different conditions of internal pressure, upstream and downstream heads of water was physically studied and analyzed by Jumaily and Salih(2005). Alhamati et al (2005a, 2005b) determined the coefficient of discharge for inflatable dams from the experimental data under different overflow heads and internal pressures for air inflated dam and also analyzed the behavior of air or water-inflated dams physically and theoretically under different conditions of internal pressure, upstream and downstream water depth. Tam (2011) in his note, reviewed the problems associated with the application of inflatable dam technology. Problems like damage due to flow-induced vibration, inflation, deflation, vandalism and due to objects carried from upstream of the weir were discussed.

3.2 Indian Experience of Inflatable Dams

India's first rubber dam was built in 2005 on Janjhavati River. Construction of Jhanjavati rubber dam was completed in six months. Two rubber dams on Musi River in Hyderabad, one kilometer apart, near the A.P. High Court and at the Salar Jung Museum (length 73m and height 1.30m) were constructed in 2008. These two rubber dams are not presently operational because of lack of pure water in Musi River. Islam and Arun Kumar (2018) has described the application of Rubber Dam to enhance the storage capacity of the 59 reservoirs of national importance by about 12.8km^3. Recently rubber dam has also been constructed at Gorakhpur, Uttar Pradesh to store the post monsoon water for fertilizer factory. It has also been established that the capital cost of rubber dam for span more than 40m is less as compared to a conventional gated structure.

4.**Design of Rubber Dams**

Compared to conventional water retaining structure having gated and un-gated spillways and weirs to release the surplus water, such as dams and barrages, rubber dam is a different and unique type of hydraulic structure. These are not dams, but structures which are made of high strength fabric adhering with rubber, which forms a ballooned rubber bag when filled with water or air and are anchored to the concrete floor, and is used for water storage. These types of dams are placed across channels, streams and medium sized rivers to raise the upstream water level when inflated and thus play a vital role in storing the water.

4.1 Forces Acting on Membrane of the Dam

The forces acting on the dam under the rubber hydrostatic conditions are:

1. Internal air or water pressure.

2. Upstream water pressure.
3. Downstream water pressure.
4. Weight of dam material.

The forces acting on air-inflated and water-inflated dam are shown in Figure 5.

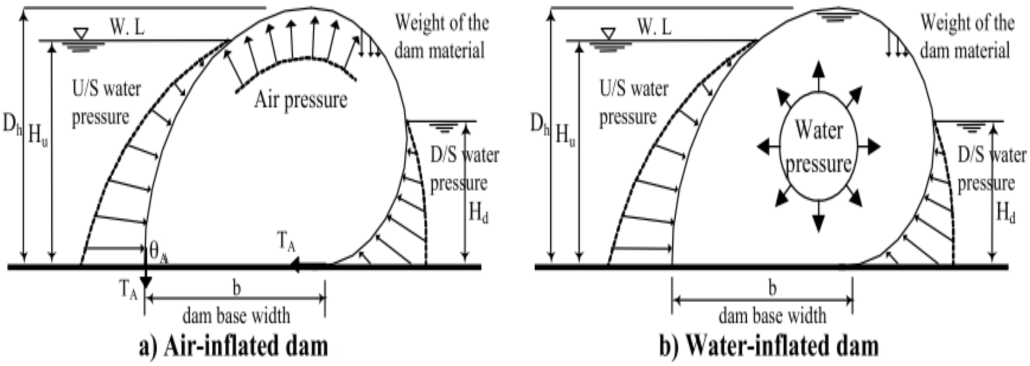


Fig 5: Forces acting on Rubber Dams (hydrostatic condition) (Alhamati et al., 2005a,b)

4.2 Calculation of Overflow Height and Coefficient of Discharges

The coefficient of discharge of air and water inflated dams are determined by using following equation, Anwar (1967)

$$Cd = \frac{q}{\sqrt{2g}H^{1.5}}$$

Where C_d= coefficient of discharge, q=discharge over dam per unit length
H=overflow head as shown in Fig. 8. Its also found that value of C_d lies between 0.35-0.50.

4.3 Structural Analysis

The structural design of rubber dam comprise of:

- Assessment of the impact force on the deflated rubber fabric due to rolling of the sediments and hence thickness of the cushion.
- Estimation of the peripheral tension in the fully inflated position and to arrive at the required tensile strength of the fabric and its thickness.
- Details of fasteners, anchor bolts, etc.
- Details of the base structure, side walls, upstream and downstream protection works etc.

4.4 Vibration Analysis

Due to the flexible structure of the rubber dam, vibration takes place in the tube when the overflow and downstream water depth become more. Generally, the higher the interior pressure, the more difficult it is for the tube to vibrate. In the case of the water-filled type, the tendency is that the larger the downstream water depth, the more easily the tube vibrates. The maximum recommended overflow depths from the viewpoint of vibration are (JIID, 1989):

Air Inflation Type	h = 0.2H
Water Inflation Type (Downstream is exposed jet flow)	h = 0.5H

where h = overflow water depth (ft) and H = Tube height at time of overflow (ft)

If the expected maximum overflow depth exceeds the above-mentioned maximum, vibration is possible. A deflector (fin) should be provided to separate the nappe from the tube and will decrease predictable vibration.

4.5 Design of Civil Structures

Design of Civil Structures for Rubber Dams is relatively simple, as it is laid on concrete base and attached with the piers in the side. In general, the base is designed as raft foundation and piers are designed for the water pressure and the forces exerted by the rubber dams.

5.0 Advantages of Using Rubber Dams For Bandhara/Barrage Structures

When rubber dams are used in *bandhara*/barrage structures, it will have the following distinct advantages:

- Design of in *bandhara*/barrage structure will be more simplified because in case of small spans up to 100m, single span rubber dams can be provided, which will simplify the design of the structure.
- Provision of overflow spillway will not be needed, as the rubber dam can itself act as spillway and pass the discharge above its crest.
- A light upper structure and uniform load of rubber dam body minimize uneven foundation settlement
- Rubber dam requires light foundation leading to considerable saving in time and cost.
- Provision of Gates is eliminated, thereby eliminating their design, erection, hoisting arrangement and operation.
- The rubber dams can be deflated and inflated automatically with respect to water levels in the upstream with a provision for manual operation.
- Rubber dams are easy to maintain and repair, low project life cycle cost.
- Rubber dams are earthquake resistant and adaptable to adverse conditions and environmental friendly**.**
- Expected design life of rubber dam bladder is more than 30 years.
- Same upstream and downstream protection works shall have to be provided.
- Construction of *bandhara*/barrage structures with rubber dams can be very fast as compared to the conventional *bandhara*/barrage structure with gates.
- It has been observed that for more than 40m span, rubber dam is more economical than the conventional barrage structures besides its other advantages over the conventional one.

6. Conclusions

Number of *bandhara*/barrage structures have been constructed and planned in State of Maharashtra and other states are also considering constructing the same. Therefore an attempt has been made in the paper to describe the details of inflatable weirs (rubber dams) to be considered as one of the viable alternative, to conventional small span gated barrage structures, for conserving water in the post monsoon period. It has also been noticed that the maintenance of the gates of the conventional in *bandhara*/barrage structures as well as removing and re-fixing the gates is an issue and therefore, some *Bandhara/Barrage Structures* may become dysfunctional or may not perform to its full efficiency. It is thus recommended that the construction of *bandhara/barrage structures with rubber dams* be encouraged in various parts of India that are underlain by hard strata, as automatic inflation and deflation will provide a boon to the problem. Besides, rubber dams are suitable and economical to long span and adaptable to different side slopes, requires short construction time, structural simplicity, flexibility, proven reliability, ease of operation, easy maintenance and repair, low project life cycle cost, earthquake resistant, adaptable to adverse conditions and environment friendly.

References

Alhamati, A.A., Mohammed, T. A., Ghazali, A.H., Norzaie, J., and Jumaily, K.K.(2005a) Determination of coefficient of discharge for air inflated dam using physical model, Suranaree, J. Sci. Technol, Vol. 12 No. 1; January-March.

Alhamati, A.A., Mohammed, T. A..,Norzaie, J., Ghazali, A.H. and Jumaily, K.K.(2005b) Behavior of inflatable dams under hydrostatic conditions, Suranaree, J. Sci. Technol, Vol. 12 No. 1; January-March.

Anwar,H.O.(1967), Inflatable dams. Jl of Hyd. Div., ASCE, Vol.93 No. HY3, pp-99-119.

Binnie, A. M.(1973) The theory of flexible dams inflated by water pressure, Journal of Hydraulic Research. 11, 61--68

Bongirwar, P.L., A.G. Namjoshi, M.M. Jaiswal(2003) Dual purpose bridge structures – Crossings and storage – need of the day, Journal of the Indian Road Congress, Vol 64-3, December.

Chanson, H.(1997) A Review of the Overflow of Inflatable Flexible Membrane Dams, Aust. Civil/Struct. Engrg Trans., I.E.Aust., Vol. CE41, No.2 and 3, pp. 107-116.

Chanson, H.(1998) Hydraulics of Rubber Dam Overflow: a Simple Design Approach, Proc. 13th Australasian Fluid Mech. Conf., Melbourne, Australia, 13-18 December, Vol. 1, pp. 255-258

Choura, S.(1997) Suppression of structural vibrations of an air-inflated membrane dam by its internal pressure, Journal of Computers and Structures, Elsevier Science Ltd. vol. – 65(5), pp. 669–677.

Hsieh, J.-C. and Plaut, R. H.(1990) Free vibrations of inflatable dams, Acta Mechanica., 85 207-220.

Ingle, R. K., P. L. Bongirwar (2016) Development of Standardized Design and Drawings of a Bridge cum Bandhara System, R&D Project National Rural Roads Development Agency.

IS: 6966 (1989)-1Guidelines for hydraulic design of barrages and weirs, Part 1: Alluvial Reaches, Bureau of Indian Standards, New Delhi.

IS: 11130(1984)-Criteria for Structural Design of Barrages and Weirs, Bureau of Indian Standards, New Delhi.

IS:4497 (1968) -Criteria for design of hydraulic jump type stilling basins with horizontal and sloping apron, Bureau of Indian Standards, New Delhi.

Ishimura, Y. (1995) Design and installation of inflatable rubber weir, International R and D conference, CBIP, New Delhi.

Islam, Shahid ul and Arun Kumar (2018) Rubber Dam for enhancing the Storage and Hydropower Generation Potential of Existing Dams. International Dam Safety Conference – 2018, DRIP, Thiruanathapuram, Feb 23-24, 2018.

Joshi, C. P., R. K. Ingle et al(2018) Bridge cum Bandhara- An Urgent Need of Time, Journal of the Indian Road Congress, Vol 79-2, April-June.

Jumaily, K. K. and Salih, A.A.(2005) Analysis of Inflatable Dams under Hydrostatic Conditions, Journal of Engineering and Development, Vol. 9, No. 3, ISSN 1813-7822.

Kale, Sagar A. and P. K. Deshpande(2018) Analysis of Fibre-Reinforced Plastic Needle Gate for K.T. Weirs, International Journal of Innovative Research in Advanced Engineering Issue 7, Vol. 5.

MoRTH, 2017, Construction of a bridge cum barrage structures on National highways serving dual purposes i.e. to cross the water body as well as to store water on upstream side - reg., Notification of Ministry of Road Transport & Highways, dated April 18, 2017.

Prachi S. Tetu, R. K. Ingle, P. L. Bongirvar (2015) Bridge Cum Bandhara – A Crossing and Storage Bridge Structure, International Journal of Mechanical and Production Engineering, Volume 3, Issue7.

Tam, P.W.M.(1997) Use of rubber dams for flood mitigation in Hong Kong, Journal of Irrigation and Drainage Engineering, Vol. 123. No.2. ASCE.

Tam, P.W.M.(1998a) Application of inflatable dam technology--problems and countermeasures, Canadian Journal of Civil Engineering; 25, 383-388.

Tam, P.W.M. (1998b) Use of inflatable dams as agricultural weirs in Hong Kong, Journal of Hydraulic Engineering, Vol. 124, No. 12, December, ASCE.

Watson, L.T., Suhermanb, S., Plaut, R.H. (1999) Two dimensional elastica analysis of equilibrium shapes of single anchor inflatable dams, International Journal of Solids and Structures.

Watson, R.(1985) A note on the shapes of flexible dams, Journal of Hydraulic Research, 23:2, 179-194.

Wu, P.H. and Plaut, R. H.(1996) Analysis of the Vibrations of Inflatable Dams Under Overflow Conditions, Thin-Walled Structures Vol. 26, No. 4, pp. 241 259, Elsevier Science Ltd

Zhang, X.Q., Tam, P.W.M., and Zheng, W. (2002). Construction, operation, and maintenance of rubber dams, Canadian Journal of Civil Engineering. 29: 409–420.