10/19/94
RGP

RUBBER DAM

INTRODUCING THE

BRIDGESTONE RUBBER DAM

August 1989

BRIDGESTONE CORPORATION
1-10-1 Kyobashi
Chuo-ku, Tokyo 104

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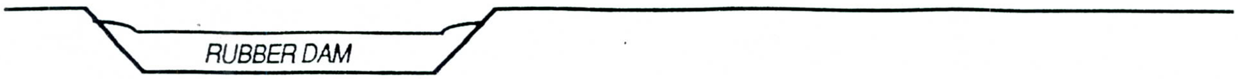

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CONTENTS

1.0 A DIFFERENT APPROACH TO WATER MANAGEMENT

Those who find the *BRIDGESTONE* Rubber Dam an intriguing idea may nonetheless feel uneasy with something as different and seemingly contradictory as a dam made of rubber and raised with air. However, contrary to being a weakness, the flexible nature of inflatable dams is the source of many of their benefits while the quality materials and advanced design of the *BRIDGESTONE* Rubber Dam make a mere interesting concept a viable alternative to conventional water management systems.

The weight and kinetic energy of water make it one of civil engineering's greatest challenges. The traditional approach of confronting the force of water "face to face" through greater rigidity and strength is not the only nor necessarily best approach.

The *BRIDGESTONE* Hi-Seas Fish Cage is a noteworthy example of living with, rather than confronting, the force of water. The aquaculture industry has traditionally raised fish in rigid wood, metal and aluminum cages until maturity for consumption. Such rigid structures, requiring placement in protected waters, are sometimes destroyed by rough seas with the consequent loss of stocks. The *BRIDGESTONE* solution to this problem was not to meet the ocean's force with greater strength and rigidity but to lessen its effect with an energy-absorbing rubber frame from which an enclosure net hangs. Accepted worldwide, this approach is revolutionizing aquaculture as flexible frame fish cages can be placed in open water and offer greater farming capacity than previously possible.

While a Rubber Dam is not a fish cage, you should see in this pamphlet that it relies on the same principle of harmony with its environment to provide a practical alternative to conventional approaches.

It is wise to be skeptical about radical approaches to age old challenges, yet skepticism means to explore with a skeptical mind, to question but not to reject outright. *BRIDGESTONE* is not selling Rubber Dams but rather providing information so that you may make your own informed decision. It is content to allow the concept and its product speak for themselves.

2.0 BRIEF HISTORY OF THE INFLATABLE DAM

2.1 Birth of the Idea

As necessity is the mother of invention, the inflatable dam was developed to fill a need unsatisfactorily met by existing systems. Norman Imbertson, chief operations engineer for the Department of Water and Power of the City of Los Angeles, conceived the idea of the Imbertson Inflatable Gate (Fabridam) in 1956. At the time, flashboards and steel gates were used in the Los Angeles River to channel water into spreading grounds for percolation into the water table. Manpower was needed to open the flashboards and delays in their opening often resulted in flooding and gates being washed away. Flood damage required frequent replacement of flashboards, not only a costly operation but one which resulted in the loss of water until repairs could be made. The problem was solved by employing a sealed rubber body anchored to a foundation in a water-course which could be raised and lowered through the introduction and removal of water or air. This material had to withstand the stress put on an inflatable dam holding back a head of water and be resistant to wear and puncture while being flexible enough to fold flat when not in use.

2.2 Shift from Water-Filled to Air-Filled Dams

Early inflatable dams used water to fill and raise the rubber tube body. Since then, however, the pneumatic type inflatable dam has become the norm as they offer quicker raising and lowering, a simpler pump and inflation/deflation system, less maintenance, no need for a water storage reservoir, and less rubber material for a given dam height due to the relatively upright posture of air-filled dams compared to water-filled ones which, because of the weight of water, present a more oval shape. While air-filled inflatable dams presented advantages over water-filled types, they proved to suffer from greater oscillation during heavy overflow because they did not have the ballast which water provided. Increased understanding of the forces acting on inflatable dams, to be followed by advances in design, were still demanded.

2.3 Japan's Involvement

Japan plays a prominent role in the history of the inflatable dam, as its embrace of the concept has seen over 1,000 installed there, several times the combined total of the rest of the world. Reliable water control systems are a must in a country such as Japan which is effected by typhoons and flooding. When the banks of Tokyo's Tama River overflowed in 1974 due to a fixed weir, the Government scrutinized methods of controlling rivers. Safety-wise inflatable dams received a strong endorsement due to their assured automatic lowering during floods. Lower cost and less disruption of water flow, and in turn the riverbed, were also noted.

Early inflatable dams produced mixed results, with problems sometimes arising from fabric wear, damage, or oscillation of the rubber tube body. *BRIDGESTONE* encountered similar problems when it produced rubber material for the first inflatable dam installed in Japan in 1964. Unsatisfied with the performance of these early dams, *BRIDGESTONE* withdrew from the market until it could offer a superior product. The inflatable dam was a concept waiting for specialized materials and technology to realize its potential.

2.4 *BRIDGESTONE* Advances the Idea

BRIDGESTONE restarted inflatable dam research and development in 1975 when technology developed for submersible oil booms pointed the way toward a superior inflatable dam material. In addition to specialized material development, analysis based on scale model studies and actual field testing led to a more complete understanding of the forces acting on inflatable dams. The superior fabric developed from this effort, along with advances in dam design, saw *BRIDGESTONE'S* reentry into the Japanese market in 1978 and the world market in 1982. Since then recognition of *BRIDGESTONE'S* advances in this field has resulted in the installation of over 300 Rubber Dams throughout the world.

3.0 INFLATABLE DAM APPLICATIONS

Inflatable dams have found a wide range of applications throughout the world and will no doubt find additional uses in the future as they meet the specific needs of water control specialists. Refer to the supply records on the following pages for examples of applications of *BRIDGESTONE* Rubber Dams.

Current Applications:

- Head Gate for Irrigation
- Head Gate for Water Supply
- Head Gate for Low and High Potential Hydropower
- Raising Crest of Dam
- Tidal Barrier
- Recreation Basin
- Sewage Treatment
- Reservoir Spillway
- Sediment Discharge Gate
- Groundwater Recharging (Water Percolation)
- Boat Lock

3.1 INTERNATIONAL SUPPLY RECORD OF *BRIDGESTONE* RUBBER DAMS

Year	HxL meters - Spans	River/Project	Application	Location	Comments
1982	1.00 x 16.00	Dongshi River	Irrigation	Hianan, Taiwan	
"	2.75 x 30.00	Indus River	Water Supply	Sheung Shui, H.K.	Fabridam Replacement
"	2.20 x 25.00	Shashan	Irrigation	Zhanghua, Taiwan	
"	1.30 x 8.00	Chen Lili Xi	Irrigation	Zhanghua, Taiwan	
1983	2.00 x 12.34 - 3	Vaca Dam	Irrigation	Luzon, Philippines	Steel Gate Replacement
1984	1.80 x 10.00	Peinan River	Irrigation	Taitung, Taiwan	
"	2.44 x 88.70	Susquehanna River	Recreation	Pennsylvania, U.S.A.	Fabridam Replacement
1985	0.60 x125.00	Non Wai Dam	Irrigation	Khon Kaen, Thailand	Raised Crest of Weir
"	2.44 x 22.40	Felton Dam	Water Supply	California, U.S.A.	Fabridam Replacement
"	2.38 x 30.48	San Gabriel River	Groundwater Recharging	California, U.S.A.	Fabridam Replacement
"	2.44 x 88.70 - 2	Susquehanna River	Recreation	Pennsylvania, U.S.A.	Fabridam Replacement
"	2.20 x 32.00	Sung Nae	Recreation	Seoul, South Korea	In Olympic Park
1986	2.50 x 22.86	Weeks Falls	Hydroelectricity	Washington, U.S.A.	5 MW Plant
"	1.80 x107.25	Mirani Weir	Irrigation	Queensland, Australia	Weir Crest-Up
"	2.44 x 88.70 - 2	Susquehanna River	Recreation	Pennsylvania, U.S.A.	Fabridam Replacement
"	1.50 x 27.00 - 2	Gon Lau River	Irrigation	Gon Lau, Taiwan	

Year	HxL meters - Spans	River/Project	Application	Location	Comments
1987	1.60 x 8.00	Shing Chu River	Flood Control	Shing Chu, Taiwan	
"	1.53 x 35.70	Altoona City	Water Supply	Pennsylvania, U.S.A.	
"	1.83 x 61.00	San Gabriel River #4	Groundwater Recharging	California, U.S.A.	
"	2.13 x 61.00	San Gabriel River #6	Groundwater Recharging	California, U.S.A.	
"	2.13 x 39.62	Los Angeles River	Groundwater Recharging	California, U.S.A.	Fabridam Replacement
"	1.83 x 45.48 & 1.83 x 61.62	Palmer Falls	Hydroelectricity	New York, U.S.A.	Flashboard Replacement, Raised Crest of Weir
988	2.44 x 50.60 & 2.44 x 88.70	Susquehanna River	Recreation	Pennsylvania, U.S.A.	7 Span Project Completed - World's Longest
"	2.20 x 52.50	Tin Shui Wai	Tide Barrier	Hong Kong	
"	1.83 x 25.53 - 3	Pit River Dam #3	Hydroelectricity	California, U.S.A.	Large Arch Dam Crest-Up
"	0.90 X 13.50	Boddington	Mining Reservoir	Western Australia	Raised Crest of Weir
"	3.35 x 15.54 - 7	Broadwater Power	Hydroelectricity	Montana, U.S.A.	Crest-Up, Extreme Cold Weather Environment
"	1.82 x 60.97	San Gabriel #5	Groundwater Recharging	California, U.S.A.	
"	1.82 x 60.97	San Gabriel #7	Groundwater Recharging	California, U.S.A.	
"	1.82 x 73.15	San Gabriel #8	Groundwater Recharging	California, U.S.A.	
"	0.90 x 31.80	Dae Am	Irrigation	Ulsan, South Korea	
"	1.82 x 9.15	Citrus	Groundwater Recharging	California, U.S.A.	
"	2.00 x 4.42 - 2	Detroit Sewage	Sewage Flow Regulator	Michigan, U.S.A.	In Box Culvert Pipe, Fabridam Replacement
"	1.00 x 30.00	Toopuukei	Irrigation	Changhua, Taiwan	

Year	HxL meters - Spans	River/Project	Application	Location	Comments
1989	2.50 x 12.00	Uirimji	Irrigation	Chech On, South Korea	
"	2.74 x 24.38	Sand Creek	Beautification	Kansas, U.S.A.	Fabridam Replacement
"	2.03 x 84.08	Kjeldal	Navigation	Kjeldal, Norway	Replaced Needle Gate
"	2.92 x 64.40	Lunde	Navigation	Lunde, Norway	Replaced Needle Gate
"	1.60 x 16.00	Mangaonui	Hydroelectricity	Tauranga, New Zealand	Flashboard Replacement
"	3.96 x 88.77	Alameda	Groundwater Recharging	California, U.S.A.	
"	3.50 x 67.67	Rainbow	Hydroelectricity	Montana, U.S.A.	Under Contract
"	2.20 x 5.00	Fukubasen	Irrigation	Changhua, Taiwan	Under Contract
"	1.24 x 25.00	Paek-Kok-Ji	Irrigation	Je-Cheon, South Korea	Under Contract
"	1.70 x 44.00	Hafslund	Hydroelectricity	Vamma, Norway	Under Contract

- - - There are over an additional 350 Bridgestone Rubber Dams in Japan - - -

(as of August 1989)

3.2 SELECTED SUPPLY RECORD OF *BRIDGESTONE* RUBBER DAMS IN JAPAN*

Year	HxL meters - spans	River/Project	Application	Location
1979	1.50 x 40.00	Iri Gawa	Tidal Barrier	Okayama
1980	0.30 x 50.00	Ichi Gawa	Water Supply	Hyogo
1981	2.45 x 16.50	No Gawa	Water Sewage	Tokyo
1982	1.40 x 8.60	Yashiro Gawa	Sediment Control	Niigata
"	1.95 x 28.90 - 2	Hayashida Gawa	Irrigation	Hyogo
"	2.90 x 17.00	Soga Gawa	Irrigation	Nara
1983	1.35 x 8.0	Hatsuka Gawa	Hydroelectricity	Hyogo
"	1.63 x 23.30	Jo Gawa	Irrigation	Miyagi
1984	2.30 x 42.10 - 3	Naruse	Tidal Barrier	Miyagi
"	2.49 x 21.40 - 2	Suna Gawa	Irrigation	Okayama
"	2.00 x 26.00	Kawarabi Gawa	Hydroelectricity	Nara
"	2.00 x 25.00	Kobase Gawa	Irrigation	Fukuoka

*(This list is intended to give an idea of the range and sizes of Rubber Dams in Japan. In total there are some 1,000 inflatable weirs in use in Japan. Although *BRIDGESTONE* entered the inflatable weir market in only 1978 it has over 300 sites in Japan and holds a 50% market share. Complete supply list of *BRIDGESTONE* Rubber Dams in Japan available on request.)

4.0 CHARACTERISTICS OF THE INFLATABLE DAM

4.1 Description of the Inflatable Dam

In the simplest terms an inflatable dam can be described as a sealed rubber tube installed across a watercourse which is raised by filling with air or water. Conversely, lowering of the dam is achieved through discharge of its contents.

Inflatable dams are normally composed of a few basic components. The first which comes to mind is the rubber body itself, normally a laminated rubber and nylon combination which is anchored to a foundation with a clamping plate and bolt assembly. An inflation/deflation system composed of piping between the dam body and a water pump or air compressor, and an automatic deflation system triggered by rising upstream water level, complete a description of the basic components common to most inflatable dams.

4.2 Rubber Dam in Comparison with Steel Gates*

As the inflatable dam is a generally unfamiliar concept it may be best to describe it in comparison with that which is familiar. Therefore the following is a look at some aspects of inflatable dams in contrast to steel gates.*

4.21 Foundation

A noteworthy aspect of inflatable dams is their simplified foundation and structural requirements, and in this respect they differ markedly from most types of steel gates which generally demand more complex foundations. In addition, some steel gates employ submerged mechanisms and hydraulics, thus entailing bracketing and piping in the foundation, while others require overhead structures. There is also the need with some steel gates for a recess in the foundation in which gates lay when open.

*(The term "steel gate" is used as a generalized expression for a wide range of gates which are quite different from each other. However, they all have in common the use of steel shutters.)

4.22 <u>Side Slope</u>

A noteworthy difference in design between inflatable dams and steel gates is found in the ability of each system to accept the natural bank slope of a watercourse. While steel gates require side walls to meet shutters at right angles, inflatable dams can accept the natural slope of a watercourse. There are three advantages to flexibility of side slope angle, the first of which deals with ecological disruption. Dams which employ walls at right angles disrupt natural water flow when opened, thereby altering the downstream movement of water and in turn possibly effecting riverbed conditions, especially important during floods. Second, sloping side walls require fewer supporting members, less reinforcement, and simpler construction than vertical retaining walls. The third advantage is that natural slopes are more in harmony with the esthetics of a river than straight walls and thereby less of a visual offense where it is preferred that a natural appearance be maintained.

4.23 <u>Intermediate Piers</u>

An important factor reducing the cost and simplifying the foundation of inflatable dams is their need for fewer intermediate piers. Whereas steel gates normally require piers at 15-30 meter intervals, a single inflatable dam can span over a hundred meters without piers. In addition, with fewer obstructions in the form of piers, natural water flow is better maintained, thereby preserving downstream conditions while resulting in less debris entrapment as well. If esthetics is an issue it should be noted that there are no, or fewer, piers to disrupt a waterway's natural appearance.

4.24 <u>Maintenance</u>

In contrast to the periodic painting demands of steel gate structures, inflatable dams require no painting. Lifting mechanism or hydraulic systems maintenance is eliminated as well.

4.3 Potential Concerns Associated with Inflatable Dams

Due to oscillation-induced abrasion of the lower downstream area of the rubber body against its foundation, some conventional inflatable dams have suffered from premature wear. Furthermore, the manner in which these dams present a prominent bulge when resting on the foundation when deflated (see photo in 5.44), creates stress and fatigue. While holes occur on the downstream side of such dams in these weakend areas, they are rarely found on the upstream side where damage from trees and rocks might be expected to occur. Hence, conventional inflatable dams have been victims of design and material limitations more than damage by outside elements.

The problems of oscillation-induced wear and a fatigue-prone bulge in deflated dams has been solved through design changes and improved materials. A fin which causes an even nappe along the *BRIDGESTONE* Rubber Dam body has dramatically lessened oscillation, while in the deflated state the fin presents a smooth surface, rather than vulnerable bulge (see photo in 5.45). In addition, a stronger and thicker rubber material than that found in conventional inflatable dams is used. The Rubber Dam copes with all but the most severe natural elements without a problem. The only real threat is man, and in this context the likelihood of vandalism in the area in which an inflatable dam will be located should be considered. Inadvertent lowering of a Rubber Dam is unlikely, however, as a sensor system automatically adds air to a dam body if a loss of pressure is detected, thereby assuring that it will remain upright even if a leak occures.

In summary, leaks are exceptionally rare, caused by extraordinary circumstances, and are not a threat to the operation of a *BRIDGESTONE* Rubber Dam. Contrary to being fragile, a strong rubber body and its ability to absorb the impact of rocks and trees make the Rubber Dam well suited for debris-ladened watercourse environments and is why they have been selected to replace damaged steel gates and conventional inflatable dams, the operators of which saw in the Rubber Dam solutions to weaknesses found in their original systems (see Supply Record, 3.1).

4.4 CHARACTERISTICS OF RUBBER DAMS IN COMPARISON WITH STEEL GATES*

Installation Cost

- Longer Spans - fewer piers needed
- Simplified Construction - relatively simple foundation
- Any Side Slope Possible - lower side wall cost
- No Overhead Structure
- Shorter Construction Period

Maintenance/ Operation Cost

- No Painting
- Low Horsepower Motor
- No Lubrication of Mechansisms or Maintenance of Hydraulic Systems

Operational/ Environmental

- Sure Deflation, no Jamming
- Any Side Slope Possible--less disruption of normal water flow
- Fewer or No Piers--less disruption of normal water flow
- No Overhead Structure--less disruption of natural appearance

*(As there is a wide variety of steel gates, some items may not apply in some cases.)

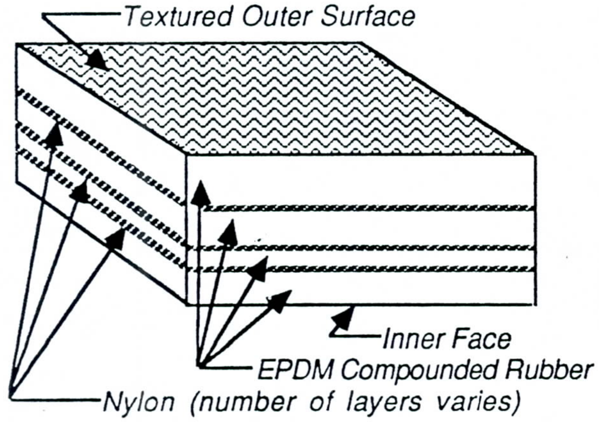
5.0 THE BRIDGESTONE RUBBER DAM ADVANTAGE

5.1 Introduction

BRIDGESTONE'S belief in the inflatable dam is joined with its commitment to fully exploit the potential this approach offers to water control. To this end *BRIDGESTONE'S* advances in dam design and materials, most noteably the inflatable dam body, have made this concept practical and the *BRIDGESTONE* Rubber Dam the preferred choice.

5.2 Construction of the *BRIDGESTONE* Rubber Dam Body

A side view drawing and photo of the *BRIDGESTONE* Rubber Dam body material are presented below. The photo is an actual 1:1 image of a 12.5*mm* thick piece of rubber body material normally used for dams between 1.7 to 2.4 meters in height.



Cross Section Photo of Bridgestone Dam Body

5.3 Manufacturing Process of the *BRIDGESTONE* Rubber Dam

Superior characteristics of the *BRIDGESTONE* Rubber Dam body are due to its manufacturing process. Conventional inflatable dams are normally laminated by semi-manual approaches employing adhesive coatings and oven curring, a process which limits adhesion of layers and thickness of the rubber body. *BRIDGESTONE* uses a sophisticated press-cure method which permits greater thickness and uniformity of the dam body.

5.4 Six Features of the *BRIDGESTONE* Rubber Dam

5.41 EPDM

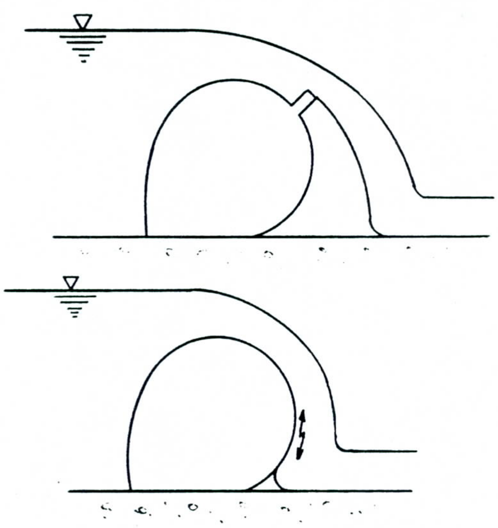
EPDM (Ethylene Propylene Diene Monomer) is a compound which, when mixed with rubber, makes it highly resistant to ozone, sunlight, and weathering. EPDM is compounded throughout the *BRIDGESTONE* Rubber Dam body, unlike most manufacturers which employ a painted coat of protector.

5.42 Thick Body

The *BRIDGESTONE* Rubber Dam has a thick body, depending on dam height between 10-16.5*mm* thick.

5.43 Fin Structure

A fin structure (top) assures the even break of cresting water from the Rubber Dam body, thereby permitting higher overflow without oscillation. Inflatable dams without a fin (bottom) do not permit as high a crest without oscillation.



5.44 Flat Body When Deflated

Apart from lessening oscillation, the Rubber Dam fin serves another function as it allows the dam body to lay flat when deflated. The lack of a bulge eliminates an area vulnerable to stress and damage, thereby lessening fatigue and wear.

← Water flow ←

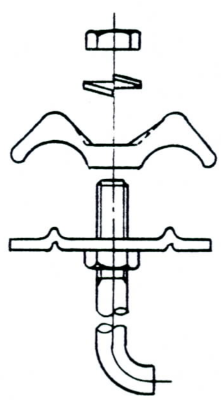
Flat·edge of deflated BRIDGESTONE Rubber Dam

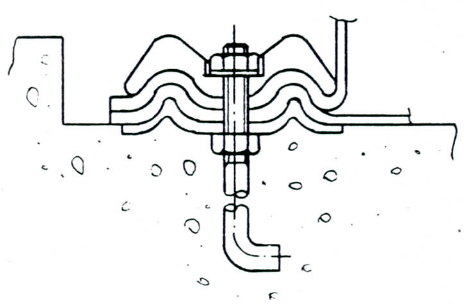
Bulged edge of deflated conventional inflatable dam

5.45 Clamping System

The manner in which the *BRIDGESTONE* clamping system anchors the Rubber Dam to its foundation while creating an airtight seal provides for simple, fast, and assured installation at the dam site. With the exception of dams which encounter over 0.2 times their height of water against the downstream side, such as tidal barriers, *BRIDGESTONE* Rubber Dams employ only a single clamping line, resulting in a very simple foundation. The nature of the clamping system itself is exceptionally simple, requires no sealants, and assures a perfect airtight seal. The standardized thickness of the *BRIDGESTONE* rubber body allows the clamp to exert equal pressure and in turn the same degree of seal along the anchor line.

BRIDGESTONE Clamping System

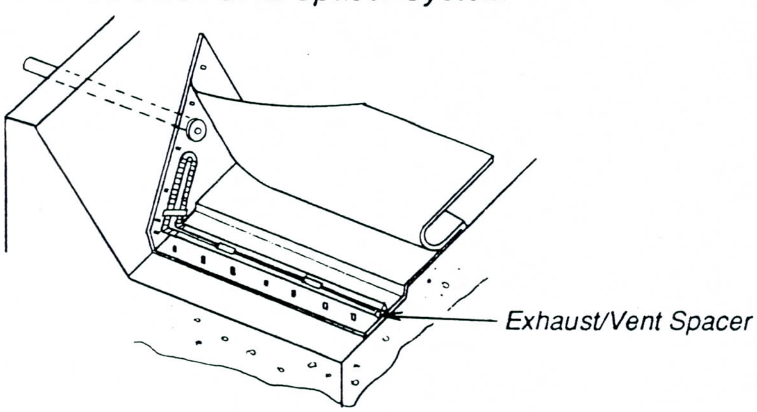




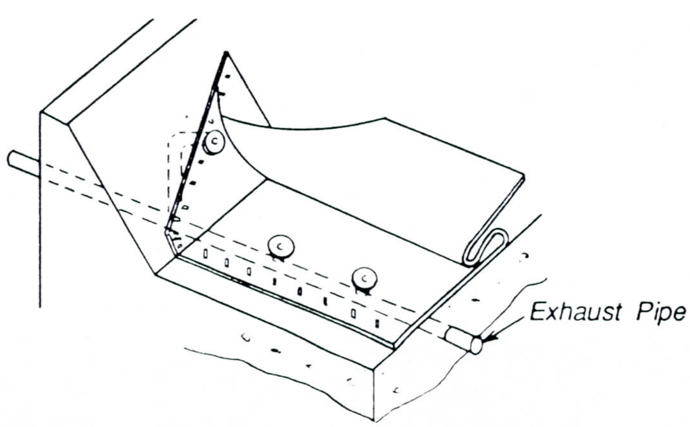
5.46 Air Exhaust System

Although *BRIDGESTONE* employs various inflation/deflation systems, the most commonly used one is noteworthy for its simplicity. As a deflating dam body settles in either the middle or sides first, deflation of the entire dam is not assured if only one exhaust exit is used on a given side, as air cut off from the exhaust outlet by a settling dam body is not able to escape. This problem is normally solved by placing a pipe in the foundation connected through a series of feeder openings to the inflatable dam to allow for the flow of air or water from the dam, an approach which entails greater foundation complexity and numerous cuts in the dam body. *BRIDGESTONE'S* most commonly employed method of assuring the escape of all air from its Rubber Dams is the employment of an exhaust vent/spacer which rests inside and along the length of the dam body and requires only one exit hole in the side wall of the foundation, as shown below.

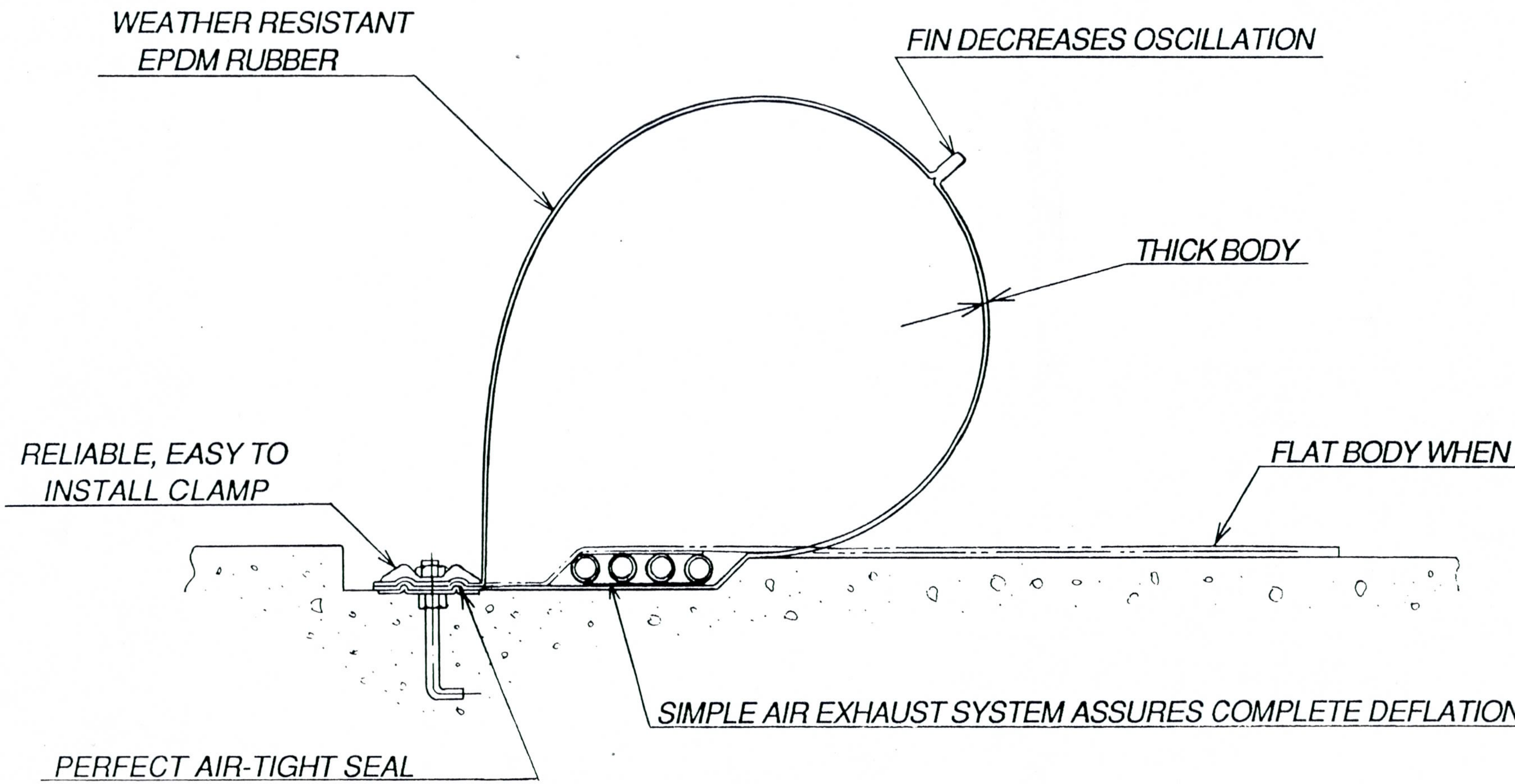
BRIDGESTONE Spacer System



Common Air Exhaust System



5.5 THE BRIDGESTONE RUBBER DAM ADVANTAGE



6.0 PRICE ESTIMATE/DESIGN FEASABILITY FORM

BRIDGESTONE is pleased to supply price estimates and evaluate project feasability. Mail inquiries to any of the addresses indicated in the front of this booklet.

GENERAL INFORMATION

Project
Name:
Location:
Application:
Owner/user:

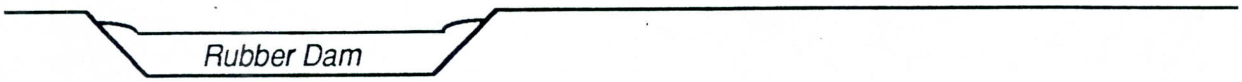
Inquirer's
Name:
Company:
Address:
Country:
Fax/Telex:

PART I (Complete for Price Estimate only)

Rubber Dam height (specify meters/feet):
Rubber Dam length (specify meters/feet along foundation):
Number of spans:
Downstream water level:

PART II (Complete for Design Fesability)

Height of overflow (crest) to go over Rubber Dam when raised:
Side slopes (where bank meets Rubber Dam):
Distance of control house from Rubber Dam:
Water quality (fresh, salt, contaminated):
Condition of riverbed (stones, sand, silt):
Will Rubber Dam be put into new foundation, existing foundation, or raise the crest of a weir or dam? Explain using sketch of intended placement and surrounding conditions. Photographs may also be helpful.



QUESTIONS & ANSWERS

about the

BRIDGESTONE RUBBER DAM

August 1989

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INDEX

1 ENVIRONMENT

1.1 Low Temperature

Are extremely low temperatures a concern with the Rubber Dam?

Rubber Dams can operate under extremely cold weather conditions. The 7 span 3.35m high x 15.54m long Broadwater Rubber Dam system in Montana, U.S.A. operates under winter temperatures down to -40°C. Furthermore, the fact that the Rubber Dam employs air and not than water as its inflation media means that there is no concern for pipes freezing. (For effect of ice see 1.3 Ice)

1.2 Temperature Extremes

Do day-night temperature extremes have an effect on the Rubber Dam?

As Rubber Dams use air pressure to keep their shape, it might be asked whether a change of pressure in a dam, and hence a change in the shape of the dam body, is caused by variations in day/night temperatures. Day/night temperature changes result in an insignificant change in the pressure and shape of a Rubber Dam as it is in contact with water which maintains a relatively constant temperature.

1.3 Ice

What effect does ice have on the Rubber Dam?

While Bridgestone has no first-hand experience with ice, as the dams it has in rivers which carry ice are deflated during the winter, inflatable dams produced by the company which pioneered the inflatable dam concept, Imbertson Engineering, have encountered ice when raised. Imberston Fabridam sections installed on the Susquehanna River in Pennsylvania have encountered heavy ice flows in their raised position for years without suffering damage attributable to ice. As this older type inflatable dam is not as thick or durable as the Bridgestone product, Bridgestone is confident that its dam will have no problems operating in a raised condition in such an environment as well. A separate analysis with photos on the effect of ice on the Susquehanna Fabridam is available.

Inflatable dams can cope with ice due to their ability to harmlessly absorb its impact and energy as the increasing pressure of ice against an area of an inflatable dam body forces a depression in it, thereby permitting ice to pass over before regaining its shape.

In the case of rivers prone to icing, the inflatable dam, with its sloping sides and need for fewer intermediate piers, is preferred over multi-pier water control systems which can block ice, causing upstream flooding, damage to piers, and jamming of gates.

1.4 Flood Areas

Are inflatable dams suitable for employment on rivers prone to flooding?

The Rubber Dam should be favorably considered for flood-prone rivers for the following reasons:

- Automatic Deflation System. The automatic deflation system does not only function without operator attendance, it is totally mechanical in operation as well. This means that no electric power, which can fail during severe weather conditions, is required. The Bridgestone system is triggered, that is the exhaust valve opened and the dam lowered to its foundation, through a mechanism activated by the rise in upstream water level.

- Debris Blockage. The greater length of individual Rubber Dam spans means fewer, if any, intermediate piers to disrupt the flow of water or catch debris during periods of high water flow.

- Side Slopes. The fact that Rubber Dams may be designed for any side angle allows them to accept the natural slope of the watercourse in which they are situated. On the other hand, steel gates normally require side walls to meet gate shutters at right angles. This can alter downstream water flow, thereby effecting a river's natural sediment base, particularly during floods.

- Submersion of Dam. Rubber Dams (the control house excluded) can be and have been totally submerged, that is, totally underwater, during floods without problem.

1.5 Polluted Water

What effect does polluted water, namely sewage and chemicals, have on inflatable gates?

The EPDM rubber compound of the Bridgestone Rubber Dam is an exceptionally stable polymer against chemical reaction. For example, such material is more resistant to acetic acid than steel and EPDM compounded rubber sheet is used to line ponds containing contaminated water and toxic wastes. If corrosion of metal components in polluted water is a concern, stainless steel fixings can be supplied. (For Rubber Dam body see 5.3 Rubber Dam Body Material and Construction and for EPDM see 5.4 EPDM and Protection of Rubber Dam Body)

1.6 Waterborne Debris

How does a watercourse featuring debris effect employment of an inflatable dam?

See 4.1 Damage from Debris.

1.7 High-Sediment Waterways

Are Rubber Dams suitable for rivers which may leave a high concentration of sediment on a deflated dam? Can a dam be inflated if it is covered with such sediment?

Sediment very rarely interferes with raising a Rubber Dam. A Rubber Dam can lift at least 0.20 times its height of sediment so, by way of example, a 2 meter (6.6') high dam can lift at least 40 centimeters (15.7") of sediment. Inflating a sediment-covered dam causes water to rise against it and wash it off. During inflation it is acceptable to exceed normal operating pressure by 1.5 times to lift the added weight of the sediment and then reduce pressure by exhausting some air once the sediment has cleared. If a lot of sediment is backed up behind a dam even after inflation, it may be advised to deflate the dam after a head of water has developed and then raise the dam again. This procedure permits water collected behind the dam to wash away sediment as it surges downstream.

1.8 Unavailability of Electricity

Can a Rubber Dam be employed in areas where electric power is not available?

Lack of electric power is no hindrance in operating a Rubber Dam as a gas powered generator can be employed to power the air compressor. An engine of around 3.5Hp producing 5 kilowatts is sufficient for an average size dam. A system which will permit the inflation of a Rubber Dam with engine exhaust can be designed. Bottled, or compressed air, is an alternative means of filling a Rubber Dam as well.

1.9 Unattended Operation

Is placement of a Rubber Dam where it will be infrequently visited a problem?

The Rubber Dam is suitable for unattended use as its automatic deflation system assures that it will be deflated and open during flood conditions even in the absence of an operator. In addition, the SCIP System (see 5.7 SCIP), which monitors a Rubber Dam's inner air pressure and adds air if necessary, insures that dams are kept in their fully inflated and raised position. If desired, the operator can add a transmitter to this system which will notify the responsible authority of changes in a dam's air pressure. A system which permits total off site remote control operation of a Rubber Dam is also possible.

1.10 Fragile River Environments

Do Rubber Dams offer any advantages in applications where there is a high concern for ecological issues such as disruption of water flow and natural scenery?

It goes without saying that the inherent function of a dam is to disrupt the natural flow of water and any water control system which is closed, i.e. blocking water, is disruptive. On the other hand an open, or deflated, Rubber Dam resting flat on its foundation provides a more natural passage for water than open steel gates. The Rubber Dam minimizes disruption over alternative control structures in a number of ways:

- The ability of Rubber Dams to accept any side slope allows them to assume the natural contour of a watercourse. The fact that the natural cross section of a river is not disrupted may result in the need for less embankment.

- The long span length of Rubber Dams permits fewer intermediate piers and hence less water turbulence which can alter the downstream bed of a watercourse.

- Less foundation works and the lack of overhead structure assure less alteration of natural scenery.

The less disruptive nature of the Rubber Dam vis-a-vis its environment was a reason it was selected for a site where environmental issues were a major concern. The Weeks Falls Rubber Dam, installed in September, 1986, is located on the South Fork of the Snoqualmie River in the Ollali State Park, east of Seattle, Washington, U.S.A. It is noteworthy as it creates a head of water for a 5 MW hydroelectric generator, is privately financed, and is located in a state park, which made environmental considerations particularly severe.

2 APPLICATIONS

2.1 Tidal Barrier

Can Rubber Dams be applied as tidal barriers?

A number of Rubber Dams are in service as tidal barriers. Stainless steel fixing components are advised for such installations. There is also a difference in the anchor system design. Due to water pressure acting on both the downstream and upstream sides of Rubber Dams used as tidal barriers a dual anchor line, which clamps both sides of the dam bladder, is necessary to counteract buoyancy of the dam body (see 7.9 Dual Anchor Line).

The non-corrosive nature of rubber makes the Rubber Dam well suited to the saltwater environments tidal barriers operate in. The largest tidal barrier in the world employing a Bridgestone Rubber Dam is the Naruse installation in Miyagi Prefecture, Japan (installation example in left hand pocket of this binder). It employs three 2.30 meter high by 42.10 meter long spans.

2.2 Replacing Old Steel Gate Systems

How are Rubber Dams used to replace old steel gate systems?

Rubber Dams can accommodate the design of almost any existing installation, thereby allowing them to replace steel gates with a minimum of modification. Refer to the one page color leaflet in the left side pocket showing the Vaca Dam in the Philippines. This dam features three separate Rubber Dam sections 2.00 meters (6.6') high x 12.34 meters (40.5') long. It would have been possible to use a single 37 meter (121.4') or so long Rubber Dam but three individual sections were used to conform to the existing design so that the steel gate superstructure would not have to be removed. In a manner similar to raising the crest of a dam (see 2.4 Raising Crest of Dam), replacing steel gates requires the installation of embedded clamping plates into the old foundation, the addition of piping, and the mounting of the Rubber Dam body.

2.3 Replacing Old Inflatable Dams

Can the Rubber Dam replace old inflatable dams?

Bridgestone has completed a number of projects involving the replacement of old water-filled inflatable dams. In such cases the original dam body is pulled off and its anchor components removed from the foundation. New embedded plates and bolts are then secured to the foundation to which a new Bridgestone Rubber Dam body is attached. It is normally possible to connect the existing water piping to an air compressor for simple conversion to the air-filled type Bridgestone Rubber Dam.

2.4 Raising Crest of Dam

Are Rubber Dams suitable for raising the crest of existing dams?

Yes. The ease of installation to existing dam crests of the Bridgestone Rubber Dam makes it especially suitable as means to add crest height to increase headwater pressure for hydroelectric production or increase reservoir storage capacity. The enclosed supply examples include a number of such facilities.

2.5 Constant Use in Raised Position

Are Rubber Dams suitable for applications in which they will be constantly in their raised position?

Bridgestone Rubber Dams are often used in their raised position as a normal mode of operation. For example, two Bridgestone dams in California, U.S.A. are kept raised to create a head of water for groundwater recharging and only lowered during the dry season or automatically during flood conditions. In another example, the new Weeks Falls Rubber Dam in Washington State, U.S.A., will be kept raised except during crises water flow conditions as it works in conjunction with a hydroelectric plant.

2.6 Frequent Raising and Lowering of Rubber Dam

Does frequent raising and lowering result in fatigue or wear in Rubber Dams?

Frequent raising and lowering does not result in increased fatigue of a Rubber Dam. As there are only a few mechanical parts in the form of valves used in conjunction with an air compressor, constant inflation and deflation causes little wear or increased maintenance demands. With respect to fatigue on the Rubber Dam body itself, load tests to 400,000 repetitions have been conducted with no appreciable deterioration of body strength (see 4.2 Life of Rubber Dam).

2.7 Infrequent Use

Are Rubber Dams recommend for applications in which they will be raised infrequently, that is, usually kept deflated on the foundation?

A number of Rubber Dams are raised only on a seasonal basis, such as in the spring and summer, to provide water for irrigation. In such cases sediment on the dam is washed away upon inflation (see 1.7 High Sediment Waterways).

3 HYDRODYNAMICS

3.1 Maximum Overflow

What is the maximum overflow recommended for a Rubber Dam?

The maximum overflow of a Bridgestone Rubber Dam is 1.4 times dam height. Therefore the crest on a 2.0 meter (6.6') high dam should not exceed 0.8 meters (2.6'). Such a high crest without significant oscillation is possible with the Rubber Dam because of its employment of a fin (see 3.7 Lessening of Oscillation). For Ogee crested weirs the maximum overflow depends on the particular shape of the weir crest, but a maximum overflow of 1.3 times the Rubber Dam height is normally advised. If demanded, design modifications can make it possible to increase the permitted overflow. Such special cases should be referred to Bridgestone for study and comment.

3.2 Watercourse Gradient

What information on the watercourse gradient is needed for the design of a Rubber Dam installation?

Bridgestone requires no information on watercourse gradient for the design of a standard Rubber Dam. Employment of the optional SCUL waterhead level control system is an exception to this. The design of this system requires data on water build-up over time behind the Rubber Dam so that it can maintain a constant head of water (see 5.7 SCUL).

3.3 Rubber Dam Air Pressure Settings

At what inner air pressure settings do Rubber Dams operate?

As can be seen in the condensed table below, the design inner air pressure of a Rubber Dam depends on its height. Note that inner pressure for a given dam height is the same as water pressure at the same depth of water.

Table 3.3 Rubber Dam Design Inner Air Pressure Settings

Dam Height	Design Pressure	Dam Height	Design Pressure
0.5 meter	0.05 (kg/cm^2)	2 feet	0.87 (lb/in^2)
1.0	0.10	5	2.17
2.0	0.20	8	3.47
3.0	0.30	10	4.33
4.0	0.40	13	5.63
5.0	0.50	17	7.37

3.4 Discharge Coefficient

What is the discharge coefficient of the Rubber Dam?

The discharge coefficient for a Bridgestone Rubber Dam is provided in the formula and graph below:

Metric:

$$Q = C \times B \times h^{3/2}$$

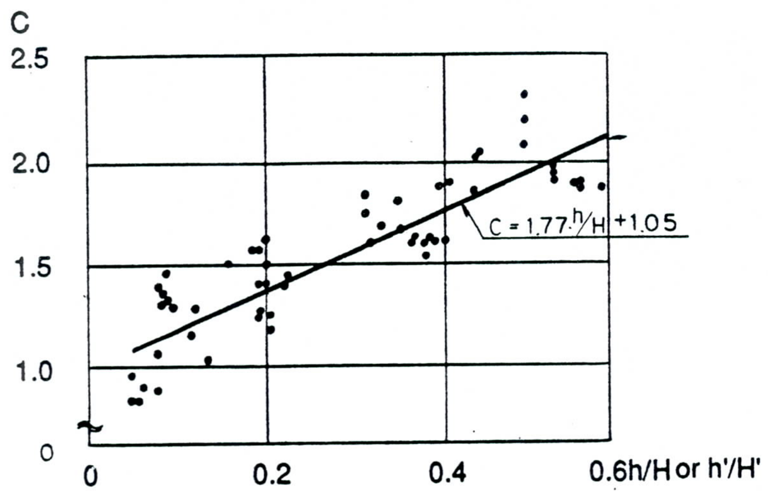
where:
- Q = Discharge volume (m^3/sec)
- C = Discharge coefficient
- B = Width of Rubber Dam (m)
- h = Overflow water depth (crest) (m)

English:

$$Q' = 1.81 \times C \times B' \times h'^{3/2}$$

- Q' = Discharge volume ($feet^3$/sec)
- C = Discharge coefficient
- B' = Width of Rubber Dam (feet)
- h' = Overflow water depth (crest) (feet)

Graph 3.4 Discharge Coefficient In Case of No Downstream Water Level Against Rubber Dam Body



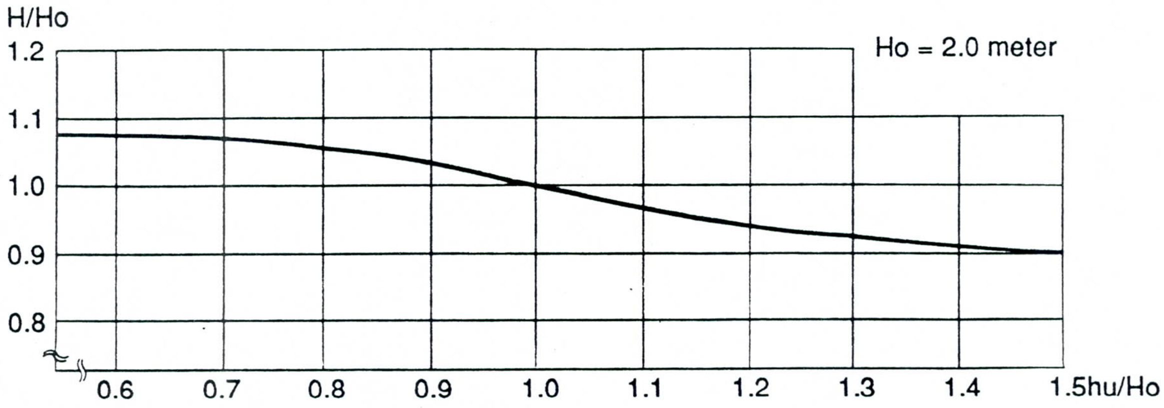
where: H = Actual height of Rubber Dam (meter)
H' = 〃 (feet)

3.5 Water Overflow and Dam Pressure/Height Relationship

The air pressure inside an inflatable dam must vary with the height of the headwater (weight of water) bearing on it. How does this effect the inner pressure and height of an inflatable dam body?

The weight of water bearing on an air-filled inflatable dam has little effect on its height. Graph 3.5A on the following page shows the relationship between the height of a Rubber Dam and a head of water, with 1.0 on the x-y axis representing water height equal to designed dam height.

Graph 3.5A Rubber Dam Height/Waterhead Height Relationship

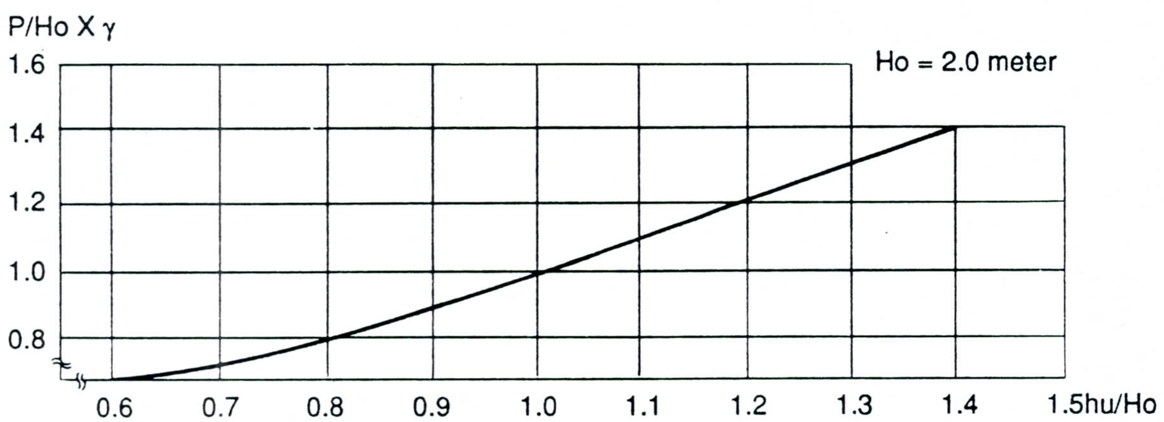


where: H = Actual height of Rubber Dam
Ho = Design height of Rubber Dam
hu = Upstream water depth

Example: 2m (6.6') high dam with an upstream water depth of 1.3 times design height (2.6m or 8.5') will have an actual height of about 1.86m (6.1') (Waterhead at 1.3 times Rubber Dam design height on x axis equals 0.93 times design height on y axis; 0.93 X 2.0m (6.6') equals 1.86m (6.1').

Graph 3.5B below shows the increase in the internal pressure of a Rubber Dam as the head of water acting against it increases. 1.0 on the x-y axis indicates inner pressure of a Rubber Dam at the designed operating height of the dam.

Graph 3.5B Rubber Dam Inner Pressure/Waterhead Height Relationship



where: P = Inner pressure of Rubber Dam
hu = Upstream water depth
Ho = 2.0 meter
γ = Specific weight of water (1 gram/cm^3)

3.6 V-Notch Effect

What is the V-notch effect in Rubber Dams?

A Rubber Dam body does not deflate evenly, that is, the crest of a dam does not remain straight and parallel with the foundation as it lowers. Discharging water rushing over a deflating dam increases the pressure acting on it, which tends to push it down in a particular place, creating a depression shaped like a "V" notch as the dam deflates to around 70% of its normal operating height. The V notch has the effect of increasing water discharge over a deflating dam and concentrating its downstream flow at the V notch position. While the V notch normally starts at the center of the dam body it often moves to either side during deflation. The occurrence of a V notch moving to the side of a dam is a function of the side slope angle. Dams with gradual side slopes keep the V notch in the center position while sharp side slopes tend to result in a V notch which shifts to the side. The V notch effect is not a practical concern as it does not result in detrimental stress to the Rubber Dam and the increase in waterflow to a particular area of the downstream riverbed is of short duration.

3.7 Lessening of Oscillation

Does oscillation effect inflatable dams, what is its effect, and how does Bridgestone deal with it?

Bridgestone's employment of a fin on the downstream side of the Rubber Dam crest minimizes oscillation of the dam body. A drawing of this fin is in *Introducing the Bridgestone Rubber Dam*, section 5.43 Fin Structure. (Also see paper *Rubber Dam: Causes of Oscillation of Rubber Dams and Countermeasures* presented by Bridgestone at the International Association for Hydraulic Research, 21st Congress, August 1985, Melbourne, Australia, available on request.)

3.8 Test Models

How does Bridgestone scale down Rubber Dam models used for testing?

Bridgestone Rubber Dam models used in tank tests are scaled down in accordance with Froude's Law.

4. DURABILITY

4.1 Damage from Debris

How susceptible is the Bridgestone Rubber Dam to damage from water-borne debris?

If rivers only carried water, most water control structures would operate trouble-free for long periods of time. However, as anyone concerned with the design, construction and operation of water control systems knows, it is less water than what it carries which presents a danger. The Rubber Dam as well must cope with a wide range of debris, several types of which are described below.

- Rocks and Boulders. Laboratory tests and field evaluations of the Bridgestone Rubber Dam have shown that it has superior resistance to wear and damage from rocks and boulders. The Rubber Dam's flexibility and energy-absorbing characteristics allow it to harmlessly dissipate the impact force of rocks rather than transmit it, as is the case with rigid materials found in conventional steel gate structures. In this context Bridgestone has applied the energy-absorbing nature of rubber to protect concrete through its development of Apron Rubber which, when attached to concrete structures, provides protection from waterborne objects.

- Logs and Trees. Often passing down streams flooded by heavy rain, logs and trees are of special concern due to their mass and impact force. The preferred way for the Rubber Dam to encounter logs and trees is deflated on its foundation so that they may pass freely, the posture it should be in during heavy flow conditions to prevent flooding. The fact that a deflated dam resting on its foundation presents a low profile with relatively smooth surfaces and few or no piers makes it less likely to catch logs and trees, often making this system preferred for watercourses where such debris are common.

As it is not uncommon for a river under normal conditions to carry logs from time to time, their effect on a raised Rubber Dam must be considered. The ability of a raised Rubber Dam to permit the passage of logs depends largely on the size of the log, whether it has any projections, and the depth of water cresting the dam. If the log is not large and a good deal of water is cresting the dam it should roll over the top. If this does not happen the log will remain on the upstream side of the dam until it's pulled out by hand or the dam is deflated to allow it to pass.

- Sediment. In terms of weight, the most common debris carried by water is sediment. Sediment carried at high velocities is not a significant problem to the Rubber Dam body as rubber is less susceptible to scouring than concrete. In the case of a watercourse likely to drop large amounts of sediment on a deflated Rubber Dam, an exceptional build-up is needed to make it impossible to raise a dam using the pressure of the air compressor specified (see 1.7 High Sediment Waterways).

- Garbage. As it comes in all kinds, shapes and sizes, garbage carried in a watercourse is difficult to classify. Inflatable dams, however, have passed all conceivable forms of debris and garbage, including automobiles, during floods. The only concern is if a dam is deflated when garbage is on its foundation, which would cause it to lay over the garbage. A quick visual check of the downstream side of the foundation prior to deflation will prevent such an occurrence.

4.2 Life of Rubber Dam

What is the serviceable life of a Bridgestone Rubber Dam body?

Bridgestone estimates the serviceability for its Rubber Dam to be over 30 years. Even though the oldest Bridgestone Rubber Dam has been in service only since 1978, this serviceability claim is a realistic estimate based on actual experience to date, accelerated age testing, long experience with a variety of rubber products, and the experience of older Fabridams. The fact that a number of Fabridams are in service after 20-25 years of use is strong support for the claim of 30 year serviceability as the Bridgestone product is a major advancement over the original Fabridam design in several key areas. The Bridgestone Rubber Dam body is almost twice the thickness for a given height and is made of a highly stable polymer compounded throughout with EPDM, instead of the rubberized canvas with a painted protective compound of the Fabridam. The employment of a fin lessens oscillation and also allows it to rest completely flat when lowered, unlike the Fabridam which displays a bulge vulnerable to damage when deflated, which has led to premature wear and damage (see 5.44 in *Introducing the Bridgestone Rubber Dam* for a photograph showing the difference between these two designs).

A separate pamphlet is available which provides details of durability and deterioration tests performed on the Rubber Dam.

4.3 Foundation Durability

Does the unique nature of Rubber Dams have an effect on foundation durability?

To the extent that a Rubber Dam is dynamic because it absorbs the energy of water and debris coming against it while rigid steel gate structures are not, the Bridgestone Rubber Dam transmits less shock and vibration throughout its foundation. This can effect the degree to which a foundation needs to be reinforced and anchored. In addition, minor shifting or cracking of the foundation, which can cause steel gates to jam, will normally not interfere with the operation of a Rubber Dam.

4.4 Vandalism

Is vandalism a concern with inflatable dams?

While the Rubber Dam can survive almost any natural conditions, firearms or knives can damage it. As should be conducted for most civil works projects, it is advised that an assessment of the threat of vandalism be performed as part of the feasability study for the installation of an inflatable dam.

Firearms tests show that bullets can pierce the Rubber Dam body. Damage in such a case is due to velocity, not mass, which explains why a bullet is a threat but a boulder is not. However, the hole created is smaller than the projectile itself, less than 1/3 the bullet's diameter, as the ellasticity of the pierced rubber causes most of the hole to fill in. This, plus the fact that the internal pressure of the Rubber Dam body is not so high, makes air loss from bullet holes slow (a separate report on the effect of bullet holes on the Rubber Dam is available). Furthermore, the SCIP system (see 5.7 SCIP), by adding air if a pressure drop is detected, assures that the upright posture of a dam is maintained even if a leak occurs.

As a knife applied with force can pierce an inflatable dam, the threat from such attacks should be considered as well. Knife cuts are more of a concern than bullet holes because the wound is larger and more difficult to repair. A separate report on the effect of bullet and knife wounds is available.

While the possibility of vandalism should be considered, Bridgestone has not experienced vandalism to any of its Rubber Dams within Japan or to those located throughout Asia or the United States.

5 SYSTEMS AND MATERIALS

5.1 Systems and Materials

Where is a general description of components and materials which make up a Bridgestone Rubber Dam?

See the enclosed *Introducing the Bridgestone Rubber Dam*, section 5.0 The Bridgestone Rubber Dam Advantage, for a general description of components and materials.

5.2 Specifications of Components and Materials

Where is a detailed specification list of the materials and components in the Bridgestone Rubber Dam?

The standard specifications of Bridgestone Rubber Dam components and materials are in a limited release document provided to clients who require it.

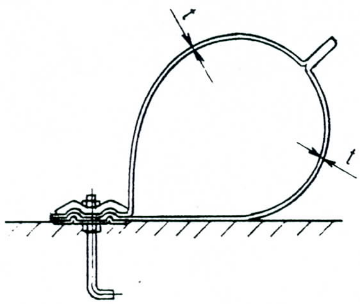
5.3 Rubber Dam Body Material and Construction

What is the construction and material of the Rubber Dam body?

As shown in the table below, Bridgestone Rubber Dams are supplied in thicknesses of between 10.0mm (3.9") and 16.5mm (6.5"), depending on the height of a dam. The Bridgestone Rubber Dam body is a highly stable polymer and EPDM compound (see 5.4 EPDM). Laminated with 2 or 3 layers of nylon canvas, depending on the height of the dam, the Rubber Dam body is produced under a heat cure process at 150°C (302°F) and 30 kg/cm^2 (426PSI) of pressure.

Table 5.3 Thickness of Rubber Dam Body

Dam Height						Thickness *(t)*
0.4m	(1.31')	↔	1.0m	(3.28')	→	10.0 mm (.39")
1.1m	(3.61')	↔	1.6m	(5.25')	→	11.5 mm (.45")
1.7m	(5.57)	↔	2.4m	(7.87')	→	12.5 mm (.49")
2.5m	(8.20')	↔	2.9m	(9.80')	→	14.5 mm (.57")
3.0m	(9.84')	↔	3.9m	(12.80')	→	15.5 mm (.65")
4.0m	(13.12')	↔	5.0m	(16.40')	→	17.5 mm (.69")



5.4 EPDM and Protection of Rubber Dam Body.

What is EPDM and why is it used in the Rubber Dam?

The protective compound EPDM, developed by Dupont in 1957, is Ethylene Propylene Diene Monomer. It is integrated throughout the rubber which makes up the Bridgestone Rubber Dam body, as compared to some other types of inflatable dams which employ a painted protective coating. EPDM is used because of its superior resistance to the effects of sunlight and ozone, which are harmful to untreated rubber. For this reason EPDM is commonly found in rubber materials which face intense sunlight and temperature extremes, such as rubber window frame linings and automotive bumpers, conveyor belts, and rubber sheet used to line toxic chemical ponds.

A separate pamphlet providing details of durability and deterioration tests performed on the Rubber Dam includes a description of EPDM and its function.

5.5 Control System Components

What components make up a standard Rubber Dam control system?

Refer to Drawing 5.10A Float Type Automatic Deflation System and Drawing 5.10B Bucket Type Automatic Deflation System for illustrations of the two inflation/deflation systems most commonly employed by Bridgestone for the Rubber Dam. In general terms the Rubber Dam inflation/deflation system is composed of an air compressor which fills the dam body with air through valves and pipes and a pressure gauge which provides a reading of the internal pressure of the dam (see 6.2 Inflation/Deflation Procedures). In addition to a manual deflation system, an automatic deflation system opens an exhaust valve when the upstream water level exceeds a predetermined setting, thereby deflating the dam to prevent flooding (see 5.10 Design and Operation of Automatic Deflation System).

Bridgestone includes within its control panel the SCIP system, which insures that a Rubber Dam will always maintain its upright posture (see 5.6 SCIP). For the precise control of headwater level the optional SCUL system is available (see 5.7 SCUL).

5.6 SCIP (System for Controlling Inner Pressure)

What is the SCIP System?

The SCIP System (System for Controlling Inner Pressure) monitors the inner pressure of a Rubber Dam and automatically turns on the compressor to add air upon detecting a pressure drop. This system assures that a Rubber Dam will maintain itself in an upright position even in the event of an air leak by monitoring its inner air pressure and adding air when necessary. In the event a leak does occur the SCIP system, by keeping the dam inflated, also permits repairs to be scheduled when water conditions permit and most convenient to the operating authority. The SCIP System is standard equipment in all Rubber Dam control systems.

5.7 SCUL (System for Controlling Upstream Water Level)

What is the SCUL System?

The SCUL System (System for Controlling Upstream Level) maintains a constant upstream water level. In comparison with the simpler SCIP System (see 5.7 SCIP), which monitors only a Rubber Dam's inner air pressure, the SCUL System sensor monitors the headwater level together with a dam's pressure. Minor adjustments to the internal air pressure through inflation and deflation are made when dictated by the headwater level sensor as interpreted by a microprocessor, thereby effecting a dam's height and increasing or decreasing the discharge rate so that the upstream water level remains constant.

5.8 Air Compressor

What capacity air compressor is used with the Bridgestone Rubber Dam?

Air compressor sizes range from a 1.9 kw unit producing 3.0 cubic meters (32.3 cubic feet) per minute to fill a 0.8 meter (2.6') high by 10 meter (32.8') long dam in 3 minutes to dual 15.0 kilowatt units acting in tandem to create greater pressure which pump 8.5 cubic meters (300 cubic feet) per minute to fill a 2.6 meter (8.5') high by 60 meter (196.9') long dam in about 65 minutes.

5.9 Difference in Air- and Water-Filled Inflatable Dams

Why does Bridgestone use air rather than water as the medium for raising its Rubber Dams?

Bridgestone uses water-filled dams for several reasons, with less maintenance as a result of pipes free from clogging with water-borne debris being the most important. Simpler design and less construction complexity are also factors. Water-filled dams require a more complex piping system and large diameter pipes and often need a storage reservoir to hold water for filling a dam in the event waterflow in the river is marginal. From an operational standpoint, air requires much less time than water to raise and lower an inflatable dam. In addition, the water in water-filled dams is at risk of freezing in cold weather use, a problem air-filled dams do not have to contend with.

In addition to operational advantages, water-filled and air-filled inflatable dams also take on different shapes which result in less rubber material needed for the air-filled type. Water-filled dams have a squat shape due to the weight of the water they contain and require more rubber material for a given height. While air-filled Rubber Dams require about 3.5 times their height in circumference, the circumference of water-filled dams is about 4.8 times height. This also means that the downstream side of the foundation must be longer to accommodate a drained water-filled type dam when it is resting on its foundation.

5.10 Design and Operation of Automatic Deflation System

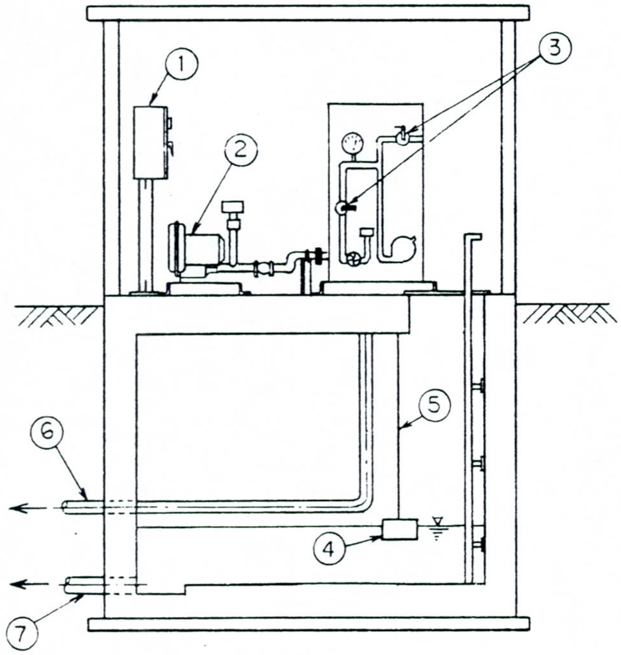
What are the different automatic deflation systems and how do they operate?

The mechanically operated automatic deflation systems used with the Bridgestone Rubber Dam are one of its primary features. These reliable systems assure that the Rubber Dam will automatically deflate to prevent flooding when the water level reaches a preset trigger level. The actual design of the system depends on the particular layout of the control house, but one of two basic types is usually used. The first type to be described uses a float riding on the upstream water level as the trigger mechanism and the second type a bucket which holds water in relation to the upstream water level. In case neither of these two systems are feasible due to placement of the control house away from or at a higher elevation than the dam, a U-type blow off pipe deflation system is possible.

Float Type Automatic Deflation System

A pipe leading from the upstream of a watercourse permits the travel of the water level to the basement of the control house (see drawing below). A float riding on this water transmits its height to an air-exhaust valve via a cable. A rising water level lessens tension on this cable until the exhaust valve is sprung open at the prescribed trigger level. This system is the simplest and most preferred as the control house basement only has to be about as deep as the maximum designated upstream water level (trigger level) when the dam is raised. This system is employed for single-span dams.

Drawing 5.10A Float Type Automatic Deflation System



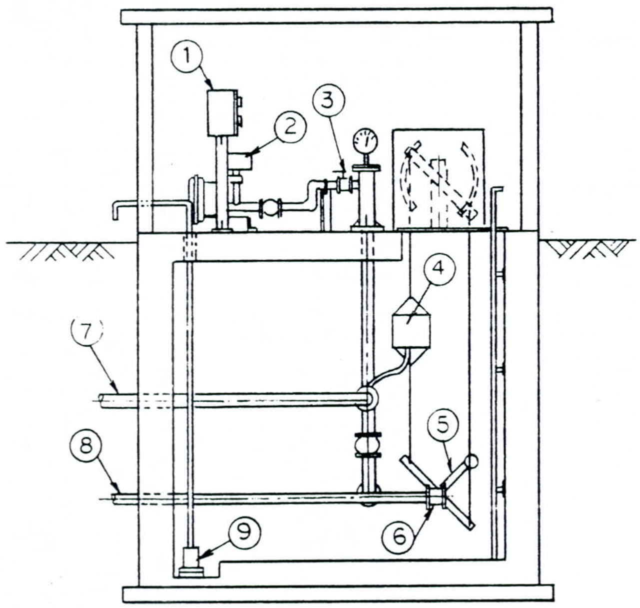
1- *Control Panel*
2- *Air Compressor*
3- *Inflation/Deflation Valves*
4- *Float*
5- *Trigger Cable*
6- *Air Supply/Exhaust Pipe*
7- *Upstream Water Level Pipe*

Bucket Type Automatic Deflation System

A water intake pipe opening on the upstream side of a dam allows the water level to be transmitted via a hose which is connected through the bottom of a bucket (see drawing below). As the upstream water level increases, water is transmitted to the bucket and when the upstream level recedes, water drains from it. The system initiates deflation when a rising upstream water level causes the bucket to fill until it reaches a set weight (the trigger level), upon which it trips a counterbalance and opens the air exhaust valve.

The bucket type system demands a deep basement in the control house due to the low position of the exhaust valve and counterweight. It is normally employed only for multi-span dams.

Drawing 5.10B Bucket Type Automatic Deflation System



1- *Control Panel*
2- *Air Compressor*
3- *Air Supply Valve*
4- *Bucket*
5- *Counterweight*
6- *Automatic Exhaust Valve*
7- *Upstream Water Level Pipe*
8- *Air Supply/Exhaust Pipe*
9- *Sump Pump*

5.11 Design and Function of Drain Pipe

Why do Rubber Dams have drain pipes and how are they designed into the dam body?

As the large mass of air pumped into a Rubber Dam can carry moisture, there must be a way of removing condensation. A single separate drain opening leading from the floor of a Rubber Dam through a pipe, when opened at time of deflation, permits water in the dam body to escape. This proceedure is rarely needed as most moisture is removed along with the air exiting a dam during deflation. The system also removes water which may collect in a dam during installation or from damage.

6 OPERATION

6.1 Operation Manual

What manuals does Bridgestone provide with its Rubber Dam installations?

Bridgestone supplies an operating manual tailored to each Rubber Dam system it supplies. The single binder includes operating procedures, inspection checklists, repair instructions and a set of blueprints.

6.2 Inflation/Deflation Procedures

What are the inflation/deflation procedures of a typical Rubber Dam?

In the case of a Rubber Dam in the open (deflated) position laying flat on its foundation, the following procedure is employed for raising it:

1. Check upstream to ensure that no equipment or people are in the area of the riverbed to be effected by rising water.
2. Close air exhaust valve.
3. Open air supply valve.
4. Start air compressor.
5. As the pressure gauge fluctuates during inflation, it is best to rely on observation of dam shape. When dam appears to have achieved proper operating shape close the air supply valve and stop the air compressor.
7. Check pressure gauge. Inflate dam further or exhaust air to achieve proper pressure level.

The procedure for deflating a raised Rubber Dam is as follows:

1. Check downstream to ensure that no equipment or people are in the area of the riverbed to be effected by increased waterflow.
2. Check that downstream side of dam foundation on which deflating dam will rest is free of obstructions.
3. If condensed water is suspected to be in the dam body, open drain pipe.
4. Open air exhaust valve.

6.3 Inflation Time

How much time is required for a Rubber Dam to inflate?

Inflation time varies by installation as it is a function of the volume of air required to inflate a dam and the capacity of the air compressor employed (see 5.8 Air Compressor). The enclosed illustrative leaflets of Rubber Dam installations provide examples of actual inflation and deflation times on their back pages under "Dam Design."

6.4 Deflation Time

How much time is required to deflate a Rubber Dam?

Deflation time is primarily a function of external pressure acting on a dam body and the diameter of exhaust pipes. Therefore, if a Rubber Dam does not have a head of water, that is no water pushing against it, it will deflate more slowly than if water is pushing against it. With a head of water, as will normally be the case, deflation time is normally about half inflation time. The enclosed illustrative leaflets of Rubber Dam installations provide examples of inflation and deflation times on their back pages under the title "Dam Design."

6.5 Possibility of Damage from Overinflation

Can the Rubber Dam be damaged as a result of over inflation?

There is no possibility of damage to a Rubber Dam from over inflation as the air compressors employed do not create sufficient pressure. In addition, the inflation system is equipped with a pressure release valve which protects the compressor from over-working if it is left running unattended.

6.6 Repair of Rubber Dam Body

How is the Rubber Dam body repaired?

If a hole is suspected in a Rubber Dam its location must first be uncovered. In the case of the upstream side of a dam this is done by checking for air bubbles coming from the dam body. The downstream side of a dam can be checked in either of two ways. If the dam is without a crest of water or has only a low crest, an individual walking along the down-stream side of the dam can inspect visually for leaks. The other approach is to deflate the dam completely and then raise it. Between the time that a dam is raised and a head of water rises and crests it, one can freely walk behind a dam and check for leaks by coating the dam body with soapy water and checking for bubbles caused by leaking air.

Once a leak has been discovered the method of repair will depend on its size and shape. Plugs are used for holes, inserted after the hole has been roughed and cleaned. Plugs can be applied with cement even if the dam is wet, that is in operation and with water cresting it. Larger cuts require an external patch applied after the surface has been roughed and cleaned and vulcanizing cement applied, all under dry conditions. Bridgestone supplies illustrated repair instructions for its Rubber Dam installations.

The SCIP System (see 5.6 SCIP), by maintaining a Rubber Dam's inner pressure, permits continued operation even if a dam has a leak. This permits the scheduling of repairs when most convenient, operations is least effected, and water conditions favorable. This system is incorporated as a standard feature in Rubber Dam control systems.

6.7 Automatic Deflation System Operation

How does the automatic deflation system operate?

See 5.10 Design and Operation of Automatic Deflation System.

6.8 Maintenance Requirements

What routine maintenance is demanded of the Rubber Dam?

Maintenance is an area in which the Bridgestone Rubber Dam compares favorably with other water control systems. The virtual lack of maintenance demanded by the Rubber Dam is largely due to the fact that a non-corrosive rubber bladder is used to block water instead of steel shutters, which require painting. The hydraulic cylinders, guiderails, lifting mechanisms, cables and pulleys of other systems are also open to corrosion and damage which the Rubber Dam, with its lack of submerged mechanical components, does not have to contend with. The only metal parts of a Bridgestone Rubber Dam under water anchor the rubber body, are fixed, and can be made of stainless steel for dams to be used in corrosive or salt water. The periodic need for a coffer dam and shut down of operations during painting is eliminated.

6.9 Special Inspection Requirements

What special inspection requirements are there for Bridgestone Rubber Dams?

Bridgestone Rubber Dams do not have special inspection requirements. A checklist of items to look at which can be incorporated into the actual operation of a dam is provided in an operating manual upon the completion of each installation.

7 DESIGNING FOR A BRIDGESTONE RUBBER DAM

7.1 Scope of Bridgestone Design Support

What is the extent of engineering design support provided by Bridgestone for its Rubber Dams?

After receiving sufficient design criteria, Bridgestone submits a preliminary design proposal to be reviewed by the client for comment. From this Bridgestone draws up blueprints covering the design of the foundation with respect to the placement of clamping plates, anchor bolts, and piping, as well as the control system, which are submitted for modification and/or approval by the client.

7.2 Foundation Design

How much foundation design work does Bridgestone do for a Rubber Dam project?

Bridgestone supplies blueprints showing the layout of Rubber Dam components embedded in the foundation, namely the placement of clamping plates, anchor bolts and piping. The anchoring of the foundation to the riverbed and foundation thickness are not provided due to their location-specific nature and differences in local design and construction practice. However, Bridgestone does supply drawings and tables which indicate recommended foundation designs as well as information on the pull-out strength of anchor bolts and stress distribution on the foundation.

7.3 Determination of Side Slope

How is the side slope angle for the Rubber Dam determined?

Bridgestone will design the side slope of a Rubber Dam in accordance with a client's request. One of the primary advantages of the Rubber Dam is its ability to accommodate any side slope, which means it can be designed to meet the characteristics of the waterway in which it is to be placed. This lack of alteration of a river's natural structure may minimize the amount of downstream water turbulence, thereby permitting less downstream riverbed and embankment shoring.

7.4 Maximum Height

What is the maximum height possible for a Rubber Dam?

The maximum height possible for a Bridgestone Rubber Dam is 5 meters (16.4').

7.5 Maximum Length

What is the maximum possible span length of an inflatable dam?

There is no limit to the length of an inflatable dam span from the standpoint of stress due to the fact that stress is evenly distributed along the entire length of the anchor line rather than concentrated at selected points. Practical limitations include shipping requirements and handling a rolled dam on site, as they can be heavy. For example, a single 2.44 meter (8') high x 88.70 meter (291') long span for the Susquehanna River in the U.S.A. weighed 14.5 metric tons.

By way of example, the longest single inflatable dam in the world is a 0.6 meter (2.0') high by 125 meter (410.0') long Bridgestone Rubber Dam span used to raise the crest of a weir in Thailand. Bridgestone also supplied a 1.8 meter (5.9') x 107.25 meter (351.9') Rubber Dam for Queensland, Australia.

7.6 Intermediate Piers

What rules govern the use of intermediate piers for inflatable dams?

As inflatable dams are capable of long spans (see 7.5 Maximum Length), the choice of intermediate piers is largely left to the project engineer. This is one area in which inflatable dams offer significant savings in cost, construction time, and foundation complexity over many other water control systems.

7.7 Control House

How much space is needed in the control house and what will it contain?

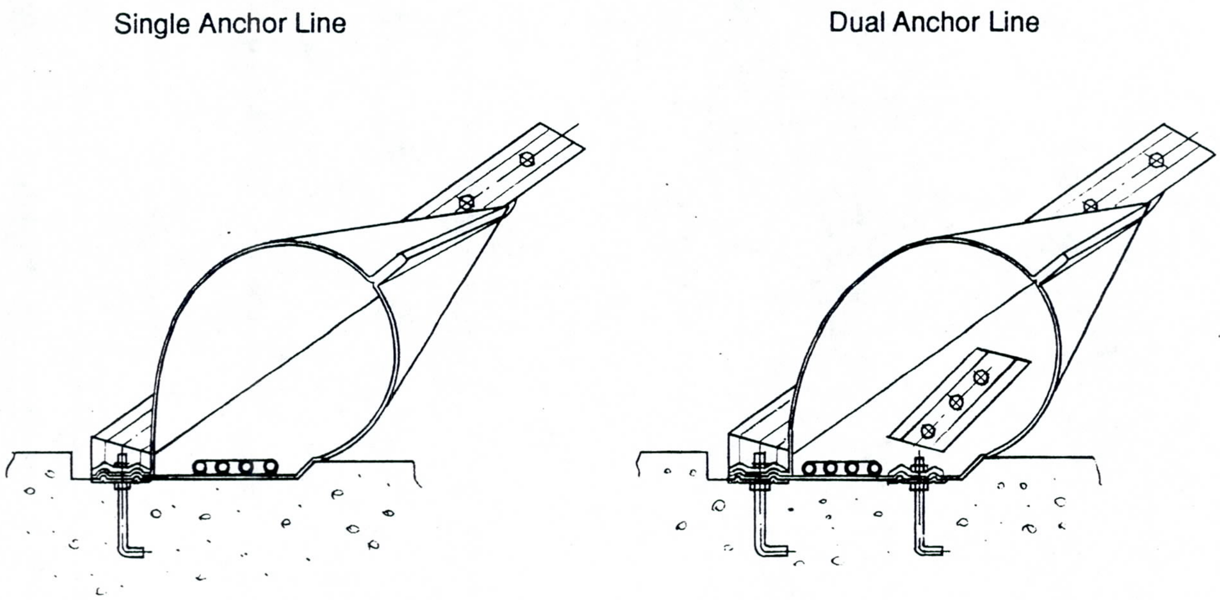
A standard control house has about 10 square meters (107.6 square feet) of floor space. The control house will contain a control panel and an air compressor with pipes leading from it, through the floor, and to the Rubber Dam body. The control house will need an underground recess for the automatic deflation system, the depth of which depends on the system used (see 5.10 Design and Operation of Automatic Deflation System).

7.8 Dual Anchor Line

What is a dual anchor line and when is it needed?

A dual anchor line is required for a Rubber Dam when the downstream water level exceeds a given dam height, such as is the case with tidal barriers. A dual anchor line is needed in such cases as water pressure acting on both sides of a dam body causes buoyancy which must be counteracted by securing both the upstream and downstream sides of a Rubber Dam. This is accomplished by employing a second anchor line on the downstream side in parallel with the upstream one. Unlike the standard design which uses no sealants, this second anchor requires sealants around the downstream side anchor bolts. Refer to the following page for a drawing comparing the single and dual anchor line systems.

Drawing 7.8 Single and Dual Anchor Line Comparison



(looking toward side slope)

8 INSTALLATION

8.1 Installation Procedure Examples

What examples showing the installation method of Rubber Dams are available?

Refer to the color leaflet "Installing the Rubber Dam, found in the left hand pocket of this binder. This leaflet shows through photographs the installation of a Rubber Dam in a new foundation and retrofit of a Rubber Dam to an existing foundation. A video tape of the Mirani Rubber Dam in Australian also shows installation procedures.

8.2 Installation Manual

What manuals are available to assist in the installation of a Rubber Dam?

Detailed installation manuals, which explain explain construction and installation procedures for the Rubber Dam through text, drawings, and photographs, are provided to assist in project completion.

8.3 Bridgestone Installation Support

Is installation supervision available from Bridgestone?

Installation supervision is available. Such assistance is normally scheduled for unrolling the Rubber Dam body onto the foundation, its clamping to the foundation, and testing; tasks usually completed in 3 to 5 working days. However, as manuals are provided (see 8.2 Installation Manual), installation should be possible without the need for Bridgestone staff on site. As to the foundation, piping and control systems,* these present nothing new to a contractor and assistance is not required during these stages.

*(Testing of the SCUL system requires a Bridgestone electrical engineer, see 5.7 SCUL.)

8.4 Skills Needed for Installation of Rubber Dam

What special skills are needed for the installation of a Bridgestone Rubber Dam?

A welder, electrician, machinist, mechanic, and contractor, who has laid concrete foundations, are needed for the construction of a Rubber Dam foundation and installation of its rubber body. None of the tasks required to install a Rubber Dam demand special skills.

8.5 Equipment Needed for Installation of Rubber Dam

What special equipment is needed for the installation of a Rubber Dam?

No special equipment which a general contractor should not be familiar with and have on hand or be able to easily obtain is needed for the installation of a Rubber Dam.

8.6 Time Required for Rubber Dam Installation

How much time is needed to install of a Rubber Dam?

While the amount of time needed for completion of civil works varies with each installation, the simple foundation of Rubber Dams normally means shorter construction time and lower costs than alternative systems. A 30 meter (98.4') long Rubber Dam should require about the following number of workers and time for installation:

Task	Staff
Supervisor	1
Welding	2
Pipe Setting	2
Earthworks	3

Time	Days
Place fixtures and pipes in foundation and perform welding	5
Build and equip control house	5
Place Rubber Dam body on foundation and clamp	4
Testing	1

Note that "Time" pertains only to those tasks specific to the Rubber Dam. Preparation of the foundation, establishing coffer dam, side embankment, etc. are excluded.

8.7 Product Shipment Method

How does Bridgestone ship a Rubber Dam?

A single 40 foot shipping container is normally used to transport a Rubber Dam and its components to a job site. Two actual examples of shipping weight and volume follow.

In the case of shipping a single 2.44 meter (8.0') high by 88.70 meter (291.0') long Susquehanna Rubber Dam span, the dam body weighed 14.5 metric tons and occupied 17.8 cubic meters (628.6 cubic feet) and equipment such as embedded and clamping plates and piping weighted 10.5 metric tons and occupied 16.0 cubic meters (172.2 cubic feet). The 2.20 meter (7.2') high by 32.00 meter (105.0') long Sung Nae Rubber Dam located in South Korea had a body weight of 5.0 metric tons which occupied 8.0 cubic meters (282.5 cubic feet) and had an equipment weight of 6.0 metric tons which occupied 10.0 cubic meters (353.1 cubic feet).

9 PROJECT DEVELOPMENT

9.1 Engineering Support

What engineering support does Bridgestone provide for Rubber Dam installations?

For engineering support for design see 7.1 Scope of Bridgestone Design Support, for installation support see 8.3 Bridgestone Installation Support.

9.2 Technical Ability Required for Rubber Dam

What level of technical knowledge is needed to install, operate, and maintain a Bridgestone Rubber Dam?

While the Bridgestone Rubber Dam is the result of advanced technology, the technical capacity needed to install and operate it is basic. Nations with limited civil engineering experience should find the Rubber Dam little problem to install and its simple operation easy for anyone to understand, which minimizes foreign involvement as local firms and workers can do most of the work. It also means that a water management system is available to meet essential needs which conventional systems may fail to meet due to high cost, difficult installation, complex operation, or demanding maintenance.

9.3 Cost Comparison with Alternatives

How does the Bridgestone Rubber Dam compare in cost with conventional systems?

This depends on so many variables that it is unlikely that actual case examples would be of any help. For example, the Rubber Dam is especially advantageous from a cost standpoint the longer its span(s) as this eliminates the need for intermediate piers common to other systems. Also, for raising the crest of an existing dam, the Rubber Dam is generally much cheaper to install than the various types of steel gate systems, many of which, given the design of the existing structure, may not be viable alternatives. However, the Rubber Dam costs more than flash boards which, on the other hand, are normally a compromise in operation efficiency, safety, and operating and maintenance cost. Moreover, in crest-up applications (see 2.4 Raising Crest of Dam), the additional power production from the increased head made possible with Rubber Dam(s) can result in rapid pay back.

By way of example, the project engineer of a hydroelectric system wrote on the cost, design, and installation considerations which led to the selection of the Rubber Dam:

> "Diversion structure alternatives were analyzed during design. The analysis considered the following types of equipment: bascule gates, slide gates, radial gates, flash boards and Rubber Dam. The slide gates and radial gates were expensive and required intermediate concrete structures which would collect debris during floods. Flash boards, while inexpensive, were judged unreliable and expensive from an operation point of view. If flash boards were lost in a flood, the project would have to be shut down.

"The decision came down to the bascule gate or Rubber Dam; both were about the same in initial cost. The deciding factor was the installation cost and time. The Rubber Dam requires about five days to install while a bascule gate would require several weeks and considerable equipment and crew. This was an important deciding factor since the regulatory agencies had required all of the in stream construction work completed during August and September. The shorter installation time also reduced the risk of having the work interrupted or disrupted by a higher than normal river flow. The Rubber Dam has the added benefit of virtually no maintenance compared to a steel structure which requires period sandblasting and painting."
(source: *MI News,* 1987 no. 2, p. 21.)

9.4 Price Estimate

How do I obtain a price quote for a Rubber Dam?

Refer to *Introducing the Bridgestone Rubber Dam,* Section 6.0 Price Estimate Request Form, which accompanies this booklet. If this is not available send information on the desired length and height of the required span(s) and a description of any special conditions to one of the addresses indicated at the front of this booklet.

9.5 Time Required for Delivery of Rubber Dam

How much time is needed for manufacture and delivery of a Rubber Dam system?

Bridgestone can have a Rubber Dam delivered to almost any site within four months of approval of specifications and blueprints.

9.6 Visiting Bridgestone Rubber Dam Site

Where can I see an actual Bridgestone Rubber Dam installation?

A supply list of Bridgestone Rubber Dams located outside of Japan can be found in Section 3.1 of the accompanying *Introducing the Bridgestone Rubber Dam.* If you wish to visit any of the dams listed, or contact persons involved with them, their location and the name of the responsible authority can be provided.

9.7 Additional Information

What additional information is available?

Please contact any of the offices listed at the beginning of this catalogue for answers to your questions.