CASE STUDY: PERFORMANCE OF RAPID RESPONSE FLOOD CONTROL SYSTEMS DURING 2011 FLOOD IN MANITOBA

Rohit Sati[1]
[1] Layfield Environmental Systems, Edmonton, Alberta, Canada

ABSTRACT
In 2011, to combat the anticipated flood situation in the province of Manitoba, a plan was put in place to increase its stock of water filled flood control dams by 9 additional kilometres. Part of the plan was to package these flood control dams into rapid response trailers that could be rapidly deployed to areas at risk. Water filled flood control dams had been used previously in Manitoba for flood control, notably in 2009. Although the flood dams worked well the deployment of the dams required transportation resources that were in short supply. The requirement was for a trailer packaged with everything needed to install a water filled dam including the dams, pumps, suction and discharge hoses, and ancillary equipment. This case history will discuss the rapid response trailer systems and present some of the challenges encountered and lessons learned during deployment of the water filled dams including ground conditions, installation and design of the dams.

RÉSUMÉ
En 2011, au Manitoba, on a mis en œuvre un plan visant l'ajout de neuf kilomètres au réseau actuel de barrages pour la protection contre les crues dans le but de lutter contre les inondations anticipées. En 2009, sept kilomètres avaient suffi pour contrôler les inondations. Même si les barrages pour la protection contre les crues ont bien fonctionné en 2009, leur déploiement avait exigé le transport de ressources manquantes. Le plan de 2011 prévoyait donc de charger le matériel nécessaire dans des remorques pouvant être rapidement et aisément déployées dans les zones à risque. Les remorques contenaient tout le matériel nécessaire pour installer un barrage, y compris les digues, les pompes, les boyaux et le matériel auxiliaires. La présente étude de cas porte sur l'organisation de ces systèmes de remorques, qui ont permis de réagir rapidement aux situations d'urgence. L'on discute également de la conception des barrages, des conditions sur le terrain, des difficultés rencontrées et de leçons apprises.

1 INTRODUCTION

The flood situation in southern Manitoba along the Red River is well documented. Each year the municipalities in the flood affected zones face new challenges to safeguard property and human life. The 2011 flood in Manitoba proved to be a difficult and lengthy event and water filled dams remained in use until August. In the beginning of 2011, the Government of Manitoba through Manitoba Infrastructure and Transportation solicited a Request for Proposal (RFP) for the purchase of Rapid Response Flood Control Systems (RRFCS). Many factors were taken into account in the evaluation of various systems such as the product stability, system adaptability, resource requirements, initial capital cost, set-up costs, and overall mobility. A major factor in the evaluation process included lead time/availability. After evaluation of the tender a design of the equipment, trailers, and water filled dams required was prepared. Project requirements grew from 9 kilometres of dams to 18 kilometres of dams as flood predictions were tallied however the delivery time for the entire project remained at 6 weeks. As part of this project a new self-contained dam design was created, tested and implemented in time to deploy with the trailers. As the RRFCT were nearing completion a special service team completed installation training with municipalities, government officials, and local crews on installation and removal techniques.

2 DESIGN OBJECTIVES

The overall objective for choosing a Flood Protection System included a safe, fast and efficient way to deploy water filled dams in flood affected zones along the river in a stipulated time frame.

2.1 Request for Proposal

In response to the RFP, the manufacturer of the dam offered RRFCT that were made up of individual mobile systems that had the ability to be deployed to multiple flood events simultaneously. An enclosed trailer was used to store the water filled dams and other equipment and materials required to deploy them, maintain them, and remove them with minimum recourses. The mobile trailer is driven to site containing multiple water filled dams for flood control.

2.2 System Configuration

The water filled dams met the requirement of the RFP. The dams were 246 feet long (75m), and were designed to wrap completely around a typical 9m x 15m structure. Figure 1 shows the proposed configuration. With this system, the driver arrives on the scene with the trailer, and 4 workers are required to deploy and fill the dam.

First the starter dam (Grey Square in Figure 1) is put in place, and filled with water.

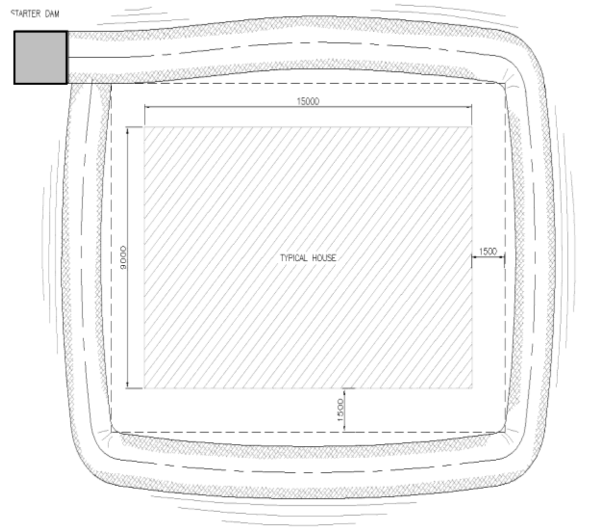

Figure 1. Schematic of water filled dam around the perimeter of a house

The pump is connected to a local water source and is primed prior to filling the starter dam. The water filled dam is deployed off of the starter dam and unrolled all of the way around the structure to be protected, and terminated onto it. A schematic of the system configuration is shown in the Figure 1. The dam is then filled with water using the same pump. Deployment time for one water filled dam (to protect a 9m x 15m structure) with 4 workers is approximately 2-3 hours.

3 DESIGN OF WATER FILLED DAMS

This section will address overall system stability of the water filled dams and presents engineering calculations to show factors of safety at different water depths.

3.1 System Stability

System Stability is key to a successful installation of a rapid deployment flood protection system. The basic principle behind the water filled dam system incorporates a dual inner tube system which acts to stabilize the entire structure. This is described in detail below. In this application 2.5 ft water filled dams where used to hold back 24 inches of water, the safety factor for overturning has been calculated at 3. As the water level nears the top of the dam, the overturning safety factor is reduced to 2.3.

The safety factor against sliding depends greatly on the coefficient of friction of the material that the dam is sitting on. In the case where it is sitting on a wet lawn, and the coefficient of friction used is 0.20 (Noon, 1994). The factor of safety against sliding is 1.33 when 24 inches of water is being held back. No anchoring is required.

Water filled dams are environmentally safe stable water barriers used to contain, divert, and control the flow of water. The design consists of two polyethylene liners contained by a single woven geotextile outer tube. When the two inner tubes are filled with water, the resulting pressure and mass create a stable, non-rolling wall of water. See Figure 2.

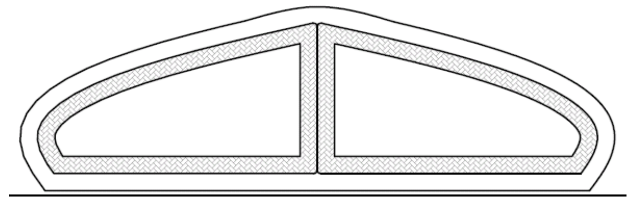

Figure 2. Schematic of water filled dam with inner tubes

A single tube filled with water will not provide a stable wall or dam as the water builds up on one side of the tube the pressure on the wall of the tube begins to increase. As a result of the building pressure, the water is pushed from one side of the tube to the other side where the pressure remains low. This can result in overturning of the barrier See Figure 3.

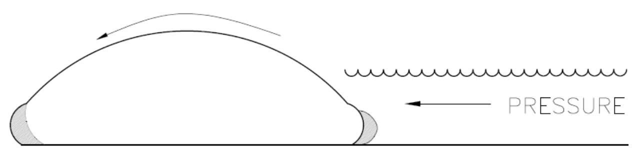

Figure 3. Common water filled dam without inner tubes

The water filled dams that were used during the flood season had the two inner tubes. As the water builds on one side of the dam, the inner tubes are unable to roll the water filled dam and thus it assumes a position of equilibrium and behaves as a solid barrier. See figure 4a.

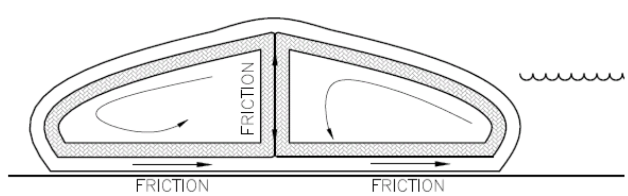

Figure 4a. Stability of water filled dam to hydrodynamic loading

In order to roll a filled water filled dam, it must be tipped over. This would require lifting all of the water mass in the first column up and over the second column. See Figure 4b. Even if the water builds to the top of the water filled dam, the pressure is far too low to provide enough force to lift the water mass and tip the water filled dam. The result is a stable, non-rolling barrier forming a solid dam.

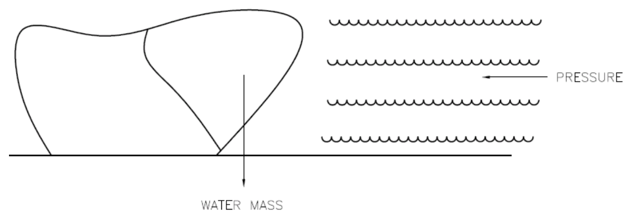

Figure 4b. Scenario of tipping over

3.2 Engineering Calculations

The following calculation shows the Water filled dam's resistance to tip.

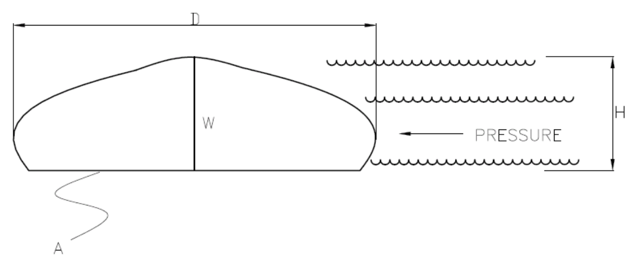

Figure 5. Schematic of the water filled dam

Assumptions:
We will assume that the inner tubes are generally rectangular when filled to facilitate the calculations. We will also assume that the water level on one side has reached the top of the water filled dam as a worst case scenario.

P = pressure
H = water depth
D = width of water filled dam
L = length of water filled dam
ρ = mass density of water
g = gravitational acceleration
γ = specific weight of water
F = force exerted on the face of the water filled dam due to pressure (P)
A = area of the bottom face of the water filled dam
W = weight of water in the inner tube
V = volume of the inner tube
$P = \rho g H = \gamma H$
$P_{avg} = \gamma (H/2)$
$A = H.L$
$F = PA = P_{avg} A$
$W = \gamma V$

The force exerted on the side of the water structure is then:

$$F = \gamma \frac{H}{2} H.L \qquad [1]$$

Having determined the force on the side of the water filled dam, we can evaluate the tendency of the water filled dam to tip. We assume point A as the pivot point and sum moments about this point. The moment created by each force, is a measure of how much the force contributes to rotating the first column of water around point A.

$$\sum M_A = W \frac{1}{2} D - F \frac{H}{3} = 0 \qquad [2]$$

or

$$\sum M_A = \rho . H \frac{D}{2} L \frac{D}{2} - \rho \frac{H^2}{2} L \frac{H}{3} = 0 \qquad [3]$$

Simplifying the expression we see that the stability of the water filled dam is dependent on the relationship between its width (D) and the depth of water (H) it must resist. The relationship above indicates the minimum width of the water filled dam to prevent it from tipping when resisting water with a depth (H) equal to the height of the water filled dam itself.

$$\sum M_A = \rho H \frac{D}{2} L \frac{D}{2} - \rho \frac{H^2}{2} L \frac{H}{3} = 0$$

$$\rho H L \left(\frac{D^2}{4} - \frac{H^2}{6} \right) = 0$$

$$\frac{D^2}{4} = \frac{H^2}{6}$$

$$\frac{D}{H} = \sqrt{\frac{4}{6}}$$

The design height for the water structures to prevent tipping would be described as:

$$D > H(0.82) \qquad [4]$$

In order to quantify the stability of the water filled dam we substitute the actual dimensions of the standard water filled dam for D and H into the equation above. The results are expressed in terms of a safety factor. The safety factor indicates how many times greater the water pressure or water depth must be in order to roll the water filled dam. Based on the current water filled dam designs, the safety factor against tipping when water levels are to the top of the structure is illustrated in Table 1.

Table 1. Height of the dam and factor of safety against tipping.

Inflated Height (in inches)	Inflated Width (in inches)	Recommended Maximum Depth (in inches)	Safety Factor Against Tipping	COF for Sliding*
12	24	8	2.44	.25
24	46	18	2.34	.26
30	57	24	2.32	.26
36	68	28	2.30	.26
48	120	36	3.48	.2
72	186	54	3.15	.19
84	282	72	4.12	.15

** See section 3.3 on Principles of Sliding Stability*

Table 2. Safety Factors and COF for sliding considering manufacturers recommended depth.

Inflated Height (in inches)	Inflated Width (in inches)	Recommended Maximum Depth (in inches)	Safety Factor Against Tipping	COF for Sliding*
12	24	8	3.65	.11
24	46	18	3.11	.15
30	57	24	3.04	.15
36	68	28	2.96	.16
48	120	36	4.06	.11
72	186	54	4.20	.11
84	282	72	4.78	.11

3.3 Principles of Sliding Stability

The second method for moving the water filled dam is to slide the entire structure. The resistance to sliding is provided by the friction between the ground and the structure. Although any type of barrier could slide along the ground if the pushing force were great enough, we will present the calculations for sliding the water filled dam in order to quantify its tendency to slide. In addition to the variables already defined we add:

μ = coefficient of friction between the water filled dam and its surface
f = friction force
N = Normal force (equivalent to weight)

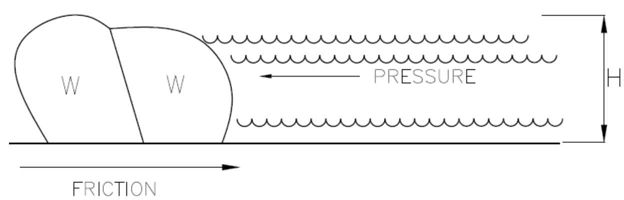

Figure 6. Schematic of frictional resistance to sliding

Assumptions: We are assuming that the supporting surface is flat. Any deviation from a flat surface will add greater opposition to sliding. Again, we assume that the inner tubes are generally rectangular to facilitate the calculations:

$$f = \mu N = \mu W \quad \sum F_x = \mu W - F = 0 \qquad [5]$$

or

$$\sum F_x = 2\left(\rho \frac{D}{2} HL\right)\mu - \rho \frac{H}{2} HL = 0 \qquad [6]$$

$$\sum F_x = 2\left(\rho \frac{D}{2} HL\right)\mu - \rho \frac{H}{2} HL = 0$$

$$\rho HL\left(D\mu - \frac{H}{2}\right) = 0$$

$$D\mu = \frac{H}{2}$$

Therefore, the coefficient of friction yields:

$$\mu = \frac{1}{2}\frac{H}{D}$$

The corresponding calculation yields coefficient of friction for sliding for various water heights. These vales are provided in the Table 1. The coefficients of friction that will allow sliding if the recommended maximum water depths are observed are mention in Table 2.

3.4 Starter Dams

One of the key improvements to 2011 flood season was our ability to install starter dams in relatively short period of time. A starter dam is made from the same materials as flood control dams but is designed to work as a platform to rest the ends of a water filled dam and to prevent water from flowing out of these dams. Typically, the starter dams are installed at every 150 meter increments; this ensures that only the 150 meter length would need to be replaced in event of a failure. The failure can result from improper placement of the dams. Two technicians can install a 3' starter dam in 15 minutes.

4 INSTALLATION DISCUSSION

4.1 Site/Ground Conditions

Flood control devices are deployed in emergency situations and there is often no time for site preparation. These devices have to be placed on unprepared subgrade. The following types of subgrade were encountered prior to the deployment of water filled dams:

- Grassy Sub-base (both levelled and slightly sloped)
- Muddy Sub-base
- Asphalt

As seen from Table 2, the Coefficient of friction that will allow sliding for this application is 0.15. The coefficient of friction for grass is 0.20 (Noon, 1994). This gives us a safety factor for our dam of 2 against sliding. This was confirmed during installation of the dams over grassy sub base where significant resistance to sliding was observed in levelled grade.

The majority of the water filled dams were placed on the top of existing earthen ring dikes to provide extra free board to prevent over topping from rising flood waters and wave action. See Figure 7. The dams were also placed along a road over asphalt in Brandon, Manitoba to keep the road open to truck traffic as the flood waters rose on both sides of the road.

4.2 Comparing efficiency of water filled dams to sand bags in a flood protection application

It is important to discuss the deployment efficiency between filling and installing a sand bag for flood protection and compare that to water filled dams. The North Dakota State University published an article titled “Sandbagging for Flood protection” that presents information on fighting flood using dikes made from sand bags (Hallevang, 2011). Based on the study they found that to build a 1 meter high and 30 meter long dike it will require 40 cubic meters of sand to fill and install approximately 4500 sand bags. This is both tedious and time consuming. In comparison, two service technicians can deploy a 30 meter long and 1 meter high water filled dam in approximately 30-45 minutes.

4.3 Construction of Water filled dams

18 kilometres of water filled dams were constructed and delivered within the six week timeline. Over 600 dams were packed into 40 cargo trailers, with an additional 200 Starter dams, 80 pumps, 80 suction hoses, and 240 discharge hoses.

Figure 7. Water filled dams providing extra freeboard over an existing earthen berm.

5 LIFE EXPECTANCY

The water filled dams that were proposed in response to the RFP were constructed using a black woven geotextile fabric as the outer skirt. The inner tube of the water filled dam was made from black polyethylene. The black pigment in these materials protects them from UV exposure. Extended exposure greater than 6 months to UV light will begin to reduce the strength of the outer skin and therefore reduce the integrity of the water filled dam structure. It is therefore important to limit the exposure to UV light while in storage or in use. Proper protection will increase the life expectancy of the water filled dam.

The water filled dams are durable and should last for multiple uses provided a regular maintenance program is implemented. The sections of the water filled dams installed should be monitored regularly for stability, possible leakage, and that rolling is not a concern.

6 CONCLUSIONS

6.1 Performance of the water filled dams

The principles used to create the water filled dams are simple yet effective. The stable non-rolling wall of water conforms to the surface beneath it creating a tight seal. The water filled dams do not tip or move even if water levels approach the top of the structure. Water filled dams provides a lightweight, reusable, and ecologically safe method of temporary water control.

Figure 8. Water filled dams protecting the highway.

Once the floodwaters of the Red River arrived the flood control water filled dams performed exactly as expected. As seen in Figure 8, the water filled dams prevented ingress of water into the highway and ensured safety of the drivers and also permit transport of goods and services in the flood affected zone.

Figure 9. Water filled dams protecting a house from flood water

The water filled dams also prevented property and other structures from flood water damage. Figure 9 shows water filled dams around the perimeter of a house defending flood waters.

6.2 Lessons Learned from the 2009 and 2011 season

The water filled dams were utilized in the 2009 flood season along the Red River. Some of the lessons learned during installation of these dams include:

- Issues related to logistics
- Resource availability
- Sand bags as Starter Dams

In 2009, water filled dams were purchased and stored in a central location in Manitoba from where they were dispatched into flood affected areas. This was a daunting task as roads in flood affected zones were cut off from the major highways. Similarly, pumps, supply and discharge hoses and other ancillary equipment to install a water filled dam were not packaged together and supplied separately. In the 2009 floods sand bags were used to create starter dams that consumed considerable amount of resources that were in short supply. Based on our experience, a 1 mtr starter dam made with sand bags can take about 350 sandbags to install. To put things in perspective, to install 10 kms of water filled dams one would need over 23,000 sand bags as starter dams in comparison to about 70 starter dams made with Geosynthetics.

The starter dams that were used to fight the 2011 flood in Manitoba were integral part of the Rapid Flood Control Systems and utilized limited space inside the trailer. Lastly, the longevity of the trailer system lies in its ability to prevent corrosion from moisture and ease of maintenance. To address this issue the inside of the flood control trailers are now offered with a water resistant finish.

ACKNOWLEDGEMENTS

The author would like to acknowledge the contribution of the following individuals towards the paper.

Andrew Mills, Director of Research and Development, Layfield Group

Mark Simpson, P.Eng General Manager, Layfield Environmental Systems

Ed Wilanowski, P.Eng Corporate Engineering Manager, Layfield Environmental Systems.

Greg Parent, Service Manager, Layfield Environmental Systems

REFRENCES

Noon, R.K (1994). Engineering Analysis of Vehicular Accidents, CRC Press, Boca Raton.

Hellevang K (2011). Sand Bagging for flood control. Extracted from North Dakota State University's web portal http://www.ag.ndsu.edu/pubs/ageng/safety/ae626w.htm on May 25th 2012.