ENCLOSURE 2

Wenck Associates, Inc., "Engineering Evaluation of Hesco Barriers Performance at Fargo, ND 2009," May 2009

Engineering Evaluation of Hesco Barriers Performance at Fargo,ND 2009

Wenck File #2283-01

Prepared for:

Hesco Bastion, LLC
47152 Conrad E. Anderson Drive
Hammond, LA 70401

Prepared by:

WENCK ASSOCIATES, INC.
3310 Fiechtner Drive;
Suite 110
Fargo, North Dakota
(701) 297-9600

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Wenck

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(Map of Levee System)

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United States Senate Committee on Appropriations, June 29-30, 2004.

1.0 Introduction

The Fargo, North Dakota area, along with its sister city across the river, Moorhead, Minnesota was recently faced with massive flooding from the Red River of the North. Due to an unusually wet fall, followed by a cold, snowy winter, the normally placid Red River was forecasted by the National Weather Service (NWS) to reach a flood crest elevation of 37 to 39 feet in Fargo by late March.(1) Unfortunately, unusual conditions continued to dominate, forcing the NWS to revise their forecast up to 41 feet, higher than any flood level on record, and predicted for only 7 to 10 days from then, instead of the originally estimated three weeks. As the river rapidly rose to nearly 39 feet, new forecasts predicted the river might even go as high as 42 or even 43 feet.

This situation, of course, generated intense concerns, and forced the rapid evaluation and subsequent use of several different methods of flood protection. To protect the City of Fargo, temporary clay dikes, which are the most common form of flood protection in the area, were used to the greatest extent possible to raise existing flood protection to at first 42 feet, but later raised to 44 feet in response to the revised forecasts. Traditional sandbag dikes were also widely used, but due to time constraints, reliability, height limitations, and availability of volunteers, the length of dikes that could be deployed could not meet all the area needs. Therefore, the US Army Corps of Engineers, who were assisting the City of Fargo, turned to Hesco Bastion, LLC for help, and to provide the remaining flood barriers. Hesco barriers have been well-tested by the U.S. Army Corps of Engineers (COE) for use as temporary flood protection, and widely used in many flood situations around the country, including New Orleans for temporary hurricane protection.

Footnote: (1) For reference, "normal" flood stage here is considered to be anything over 18 feet. The 1997 flood, called the "Flood of the Century" and which inundated Grand Forks that year, reached a stage height in Fargo of 39.6 feet. The highest level on record was 40.1 feet, reached back in 1897.

Hesco barriers are able to be installed relatively quickly, and due to this speed of deployment, approximately 10 miles of barriers were installed over a 4 to 5 day period. Fortunately, the combination of clay dikes, sandbag dikes, and Hesco barriers, together with the tremendous efforts by City of Fargo staff, National Guard, and volunteers, worked, and the City of Fargo largely escaped serious flooding.

In the aftermath of these efforts, various comments surfaced regarding the performance of the Hesco Barriers. In particular, concerns were raised about the possibility of the Hesco's sliding laterally over the ground surface due to water pressure, and the increased rate of seepage through the barriers over expected rates. Also, concerns were raised about two specific locations where Hesco's had been deployed, and significant leakage had occurred requiring emergency actions to prevent possible breaching.

Hesco Bastion, concerned about these comments, approached Wenck Associates, Inc. (Wenck) to provide an independent engineering evaluation of the performance of the Hesco barriers during the Fargo floodfighting efforts. The scope of this engineering evaluation was agreed to be as follows:

- Meet with Mr. Dennis Barkemeyer of Hesco Bastion to discuss installation procedures that were used at the various sites in Fargo.
- Evaluate photographs taken during installation of the barriers.
- Visit selected Hesco sites around Fargo to evaluate post-flood barriers.
- Interview City of Fargo/COE staff to discuss product use, problems they encountered or noted, comparison to other dikes (sand bag and clay), and comments on the products.
- Revisit dike locations where the City/COE indicated they had problems or issues.
- Evaluate product and its uses in Fargo for floodfighting in light of the frozen ground oftentimes encountered, and the soft clay soils.
- Prepare a letter report or technical memorandum that outlines the findings of the above work, and provides recommendations for future use in this environment.

1.1 PURPOSE OF EVALUATION

This independent engineering evaluation was requested by Hesco Bastion, LLC to address comments raised after Hesco units were installed in Fargo, North Dakota for combating flooding by the Red River of the North in March, 2009.

1.2 BACKGROUND INFORMATION

Hesco Bastion Concertainers® (hereinafter referred to as "Hesco"), are a structural system of linked baskets containing fill material. They provide a way of positioning and containing large volumes of earth, sand, gravel, or rock to form either temporary or long term structures. They may then be used for a variety of projects, including emergency flood protection (as at Fargo, North Dakota in 2009). The units are manufactured in various sizes and are made of welded galvanized steel mesh that are assembled with coiled joints. A polypropylene, nonwoven geotextile liner retains the fill material that is placed into the open top basket. The baskets are initially flat-packed on pallets, then extended and joined with joining pins, filled with fill material, and placed in various configurations depending on the end use. The units are lightweight, portable, and are easily deployed.

2.0 City of Fargo Uses of Hesco Barriers

2.1 NUMBER OF MILES USED VERSUS TOTAL

The City of Fargo constructed a total of approximately 80 miles of dikes using a combination of clay, sandbags, and Hesco barriers. There were approximately 10 miles of Hesco barriers deployed within the City of Fargo. The barriers were used for both primary and contingency dikes, and were placed on paved and non-paved surfaces, as well as on top of existing levees. The location and types of dikes are shown in Attachment A.

2.2 SIZES

The City of Fargo deployed two types of Hesco units, the standard and flood barriers in the 3' deep by 3' high by 15' long, and 3' deep by 4' high by 15' long sizes. The standard barriers have separation fabric dividing each barrier into five equal compartments, 3' long each. The flood barriers do not utilize the separation **fabric** between compartments, so each unit is able to have continuous fill material.

2.3 INSTALLATION RATES

Installation rates varied greatly due to the availability of fill material, and the access to the area in terms of both men, equipment, and physical access. Field personnel that were interviewed stated they typically could deploy and fill 400 to 600 feet of Hesco's per hour.

2.4 COMPLICATING FACTORS

The City of Fargo is located in the Red River Valley, formed at the bottom of former glacial Lake Agassiz. This lake deposited thick sequences of lacustrine clays and silts, which form the soils here. These soils are very fertile, but have poor engineering properties, and are prone to slippage and soil failures. Weather conditions prior to the rising of the Red River had completely saturated these soils, making conditions very muddy. Dikes then had to built on top of, and using, these saturated clay soils, often while rains continued. Subgrade conditions were thus far from ideal.

Later in the week prior to the predicted flood crest for the Red River, the weather changed again to very cold, and the area received nearly one foot of snow. These cold conditions persisted for awhile, and caused many of the soils to freeze at the surface, further complicating subgrade conditions on which the Hesco barriers (and all temporary dikes) were built.

3.0 Interviews with City and City Representatives

3.1 ISSUES RAISED AND AREAS OF CONCERN

During interviews with personnel involved with the Hesco barriers, concerns were brought up about the stability of the barriers. Some had thought that the barriers were kicking out at the bottom, leaning and possibly sliding over the soil surface. Comments were made about lines of Hesco barriers installed "straight", but then becoming ragged looking over subsequent days as though some were sliding and/or leaning, even though no floodwater had reached them as yet. Concerns were also raised about possible sliding and/or overturning of the Hesco barriers if floodwaters came up over their half-way level (approximately 2 feet vs. the 4-foot height of the barriers), especially since many were already leaning toward the water (although not installed with a noticeable "lean"). Additionally, seepage through some of the barriers had caused some concern.

Two specific locations of concern were also brought up by the City of Fargo. The first was on 5th Street South (just south of I-94), and the second was along the south side of Drain 27 (just east of I-29). It was stated that the 5th Street area had to be buttressed with material on the back side of the Hesco barriers and a section of sandbag dike, after a significant leak was found in the transition area from Hesco barrier to sandbag dike. The second was the Drain 27 area, which had shown settlement in one area where the Hesco barriers were placed on top of an existing earthen levee.

3.2 COMMENTS FROM INTERVIEWS

After hearing the above issues, Wenck interviewed several engineers that were directly involved in erecting Hesco barriers during the flood fight, as well as clay or sandbag dikes. These engineers included representatives from the City Engineering Department, and local firms, Ulteig Engineers, and SRF Engineers. Questions were asked directly about the issues raised above, and what the engineers observed, as well as about the two locations of concerns.

The first location of concern, 5th Street South, was thought to be a problem due to a sandbag dike being butted up directly to a Hesco barrier, with little or no overlap. This transition area had started to leak, so emergency crews buttressed the back side with clay to stop the excessive leakage. Field personnel thought the problem was due to the poor transition, not the Hesco units.

The second location of concern, along the south side of Drain 27, was due to water pushing through a stormwater structure and discharging rapidly out the top of a manhole. This water saturated the dike around the structure and caused a section of the dike to slump (sag), including the Hesco units on top of the dike. Field personnel packed clay over the top of the manhole, and built a small cofferdam around it to stop the leakage. Field personnel thought this issue had nothing to do with the Hesco units, only the stormwater structure.

Field personnel indicated that the amount of dikes constructed with the Hesco barriers in a short time was instrumental in protecting the city. Building the 10 miles with sandbag dikes would have been very difficult with the time and volunteers available, plus the miles already built with sandbags. Additionally, the uniformity of the dikes erected with Hesco units was thought to be very important, especially relative to sandbag dikes raised on an emergency basis by volunteers. They also noted that the units adapted to terrain changes very well. Most thought that seepage under the units was less than what a sandbag dike would be, even without the poly-sheeting used in most locations. Field personnel believed that any leaning or apparent sliding of the units was most likely due to settlement of the units into the saturated clay subsoils, as subgrade locations were often poor due to the saturated conditions, and then the snow and freezing conditions, rather than actual sliding.

4.0 On Site Evaluations by Wenck Associates, Inc.

4.1 VISUAL INSPECTION

Visual observations were made of Hesco barrier installations at 5th Street South, Drain 27, the Fargo Country Club golf course, 40th Avenue South, Timberline addition, and the Harwood Groves area.

The 5th Street Hesco barriers were difficult to inspect for the concerns that were brought up by City staff. The area behind the Hesco barriers and sandbag dike had been filled in with sand after issues were first brought up. During interviews with field personnel it was determined that this area most likely didn't have the sandbag dike tied in sufficiently to the Hesco barriers. It was stated that the sandbags butted up directly to the Hesco units, instead of using a sufficient overlap to adequately protect the transition.

In the Drain 27 area, Hesco barriers were placed on top of an existing earthen levee. Settlement was noted in a section of the earthen levee just east of I-29 on the south side of the drain. Interviews and inspection showed that this appeared to be due to an existing storm sewer running through the existing earth levee and discharging to the drain. After installation of the Hesco barriers and noticeable settlement in part of the dike, it became apparent that a storm sewer structure located within the earthen levee was discharging water through the top of the structure and onto the earthen levee. This leakage completely saturated the area and allowed the Hesco barriers to settle into the earthen levee, as well as causing settlement of the levee itself.

The Fargo Country Club area consisted of Hesco barriers being deployed through the golf course. Evidence of soft soils were noted from the ruts left by equipment used to deploy and fill the Hesco barriers.

The 40th Avenue south area had Hesco barriers installed on top of an existing earthen levee. A concern of the barriers leaning was made during interviews. Measurements showed that the barriers were leaning approximately 3.5” in 4 vertical feet. These barriers have also settled on the water side approximately a ½”, and none on the dry side.

The Timberline area consisted of Hesco barriers that were used for primary temporary protection. Barriers were placed in residential backyards along a drainage channel. It was noted that some of the Hesco barriers were leaning. Measurements were made at a few locations, which showed 6.5” of lean in four feet. Field personnel indicated that the barriers were leaning during installation because of the lay of the land, and that they had performed field measurements over a couple of days and determined that the units had not shown any movement.

The Harwood Groves area consisted of Hesco barriers installed in a 2 – 1 configuration (base 2 barriers wide with a single unit placed on top). The Hesco barriers were providing secondary protection is this area. Clay had been placed up to the top of the base units on the backside.

5.0 Technical Evaluations

This section discusses three different traditional failure mechanisms for retaining structures such as the Hesco barriers; sliding, overturning/tipping, and seepage, and the Hesco barriers resistance to them. Within each of this subsections, references to previous studies are introduced and discussed (if available), followed by an independent review.

5.1 SLIDING

Sliding of a retaining system (i.e., the Hesco barriers) is most simply defined by Equation 1, which relates the resisting and driving forces for sliding to the overall factor of safety against sliding. For long-term situations (i.e. permanent walls), it is considered good practice to have a factor of safety (FS) against sliding equal at least 1.5, meaning that the resisting forces are 50% greater than the driving forces. For short-term situations, applicable to temporary flood protection dikes, this acceptable factor of safety is 1.3.

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = \frac{(F_v \tan\delta) + cL}{F_h} \qquad \text{(Equation 1)}$$

Where: F_v = Weight of basket (1' "slice" of basket) minus uplift force (lbs/ft)

δ= Interface friction coefficient

c = Cohesion, or undrained shear strength (lbs/ft^2)

L = Length, or basket depth (ft)

F_h = Horizontal force from water (lbs/ft)

5.1.1 Review of Available Information

A report issued for the United States Senate Committee on Appropriations, dated June 29-30, 2004, discussed possible sliding, and is provided in Attachment B for reference. This report discusses the resistance to sliding based on different types of fill soils (fine sand, coarse sand, and gravel), and different types of surfacing materials (earth, concrete, and grass).

Table 1 of the referenced report, shown below, gives the interface coefficients of friction for the fill soils and surfacing materials.

Table 1. Interface friction information

Fill Type	Interface Coefficient of Friction					
	Earth		Concrete		Grass	
	tan δ	δ	tan δ	δ	tan δ	δ
Fine Sand	0.58	30	0.35	19	0.30	17
Coarse Sand	0.67	34	0.45	24	0.35	19
Gravel	0.78	38	0.60	31	0.40	22

Note: tan δ = Tangent (δ) = μ or the friction coefficient.

Using the above information, the authors of the referenced report compiled factors of safety against sliding for 30 different load cases, considering various structure heights, flood heights, fill types, and surfacing materials. This information is provided in Attachment B, but most of the cases are shown again (albeit in a different order) in Table 2 below. Information not included in Table 2 are the cases where the flood height was higher than the structure height, and also cases where the fill material was gravel (because site observations in Fargo noted that only sand was used to fill the Hesco Concertainers).

Table 2. Factor of safety against sliding for various load cases organized by flood height[1]

Case	Flood Height	Structure Height	Surface Type	Fill Type	FS (full uplift)	FS (no uplift)
4	3	3	Concrete	Fine sand	0.8	1.2
5	3	3	Concrete	Coarse sand	1.2	1.6
1	3	3	Earth	Fine sand	1.3	1.9
2	3	3	Earth	Coarse sand	1.7	2.4
7	3	3	Grass	Fine sand	0.7	1.0
8	3	3	Grass	Coarse sand	0.9	1.3
13	3	4	Concrete	Fine sand	1.6	2.0
14	3	4	Concrete	Coarse sand	2.3	2.9
10	3	4	Earth	Fine sand	2.6	3.3
11	3	4	Earth	Coarse sand	3.3	4.2

Case	Flood Height	Structure Height	Surface Type	Fill Type	FS (full uplift)	FS (no uplift)
16	3	4	Grass	Fine sand	1.4	1.8
17	3	4	Grass	Coarse sand	1.8	2.2
22	4	4	Concrete	Fine sand	0.8	1.2
23	4	4	Concrete	Coarse sand	1.2	1.6
19	4	4	Earth	Fine sand	1.3	1.9
20	4	4	Earth	Coarse sand	1.7	2.4
25	4	4	Grass	Fine sand	0.7	1.0
26	4	4	Grass	Coarse sand	0.9	1.3

(1) Red highlighting means the factor of safety is not acceptable (below 1.0).
Yellow highlighting means that the factor of safety is only marginally acceptable (between 1.0 and 1.3)
Blue highlighting means that the factor of safety is acceptable (greater than 1.3) for short-term conditions.

This table indicates that the authors found acceptable or marginally acceptable factors of safety against sliding are achievable for many of the cases analyzed, including **all** of the cases where the flood height was 3 feet, the containers were 4 feet high, and the containers were placed on earth.

5.1.2 Independent Review

The above calculated factor of safety values assume that uplift pressures exist and will reduce the available resisting force. This is a conservative opinion, because it is likely that even if a layer of sand is frozen at the base of the Hesco Concertainer, enough pore-water pressure would be dissipated so as to minimize or negate the resulting uplift pressures (from buoyancy of the structure vs. the underlying soils), simply based on the fact that the drainage path for seepage beneath the unit is no longer than about 3 feet.

An analysis was also completed for a two layer Hesco system (consider a double container base and a single container top) using the same theories as used to develop Table 2 (i.e., forces acting on a one-foot cross-section of barrier). This information is provided in Table 3, below.

Table 3. Factor of safety against sliding for various load cases organized by flood height[1,2]

Case	Flood Height	Structure Height	Surface Type	Fill Type	FS (full uplift)	FS (no uplift)
4	6	6	Concrete	Fine sand	0.5	0.9
5	6	6	Concrete	Coarse sand	0.8	1.2
1	6	6	Earth	Fine sand	0.9	1.4
2	6	6	Earth	Coarse sand	1.1	1.8
7	6	6	Grass	Fine sand	0.5	0.8
8	6	6	Grass	Coarse sand	0.6	1.0
13	7	8	Concrete	Fine sand	0.7	1.1
14	7	8	Concrete	Coarse sand	1.1	1.6
10	7	8	Earth	Fine sand	1.2	1.9
11	7	8	Earth	Coarse sand	1.6	2.4
16	7	8	Grass	Fine sand	0.6	1.0
17	7	8	Grass	Coarse sand	0.9	1.3
22	8	8	Concrete	Fine sand	0.5	0.9
23	8	8	Concrete	Coarse sand	0.8	1.2
19	8	8	Earth	Fine sand	0.9	1.4
20	8	8	Earth	Coarse sand	1.1	1.8
25	8	8	Grass	Fine sand	0.5	0.8
26	8	8	Grass	Coarse sand	0.6	1.0

(1) Red highlighting means the factor of safety is not acceptable (at or below 1.0).
Yellow highlight means that the factor of safety is only marginally acceptable (between 1.0 and 1.3).
Blue highlighting means that the factor of safety is acceptable (greater than 1.3) for short-term conditions.

(2) Overall system is set up as 2 containers on the bottom and one on top.

This table shows that careful engineering is needed before installing such a two-tier system, as acceptable factors of safety are achievable for much fewer cases than the single tier system. These relatively low calculated factors, together with some concerns about the single tier system, especially with flood height equal to barrier height, showed that some actual field testing of the barriers should be done. This was largely due to actual field experience not squaring well with theory.

5.1.3 Field Testing

In response to the concerns raised above, field test analyses were performed on partial sections of the Hesco units to determine the sliding resistance to lateral forces. These analyses were done in Fargo on April 9, 2009, and reported on in a separate technical memo to Hesco Bastion LLC, dated April 30, 2009. Tests on 3' deep by 3' wide by 4' high sections were conducted with the filled units placed on various base surfaces. The total amount of force required to move the unit was recorded, along with the volume and weight of the filled unit. This allowed the actual friction coefficient and factor of safety to be computed in a real-life environment. An independent soils laboratory performed soil analyses on submitted fill samples, and gave a unit weight and gradation of the fill sand for both uncompacted and medium compacted samples (see Tables 4, 5 and 6). [Note: The field tests did not consider overturning, bearing capacity of the underlying soils, or seepage rates of the units.]

Table 4. Field Data Collected

Test Surface	Test #	Hesco Unit ("Basket") Volume	Load Cell Reading	Basket Weight @ 89.5 PCF Sand	Basket Weight @ 102.0 PCF Sand	Calculated Friction Coefficient if Sand is 89.5 PCF	Calculated Friction Coefficient if Sand is 102.0 PCF
		(ft^3)	(lbs)	(lbs)	(lbs)		
Grass	1	48.8	2700	4387	4978	0.62	0.54
Grass - Muddy	2	44.0	3300	3956	4488	0.83	0.74
Grass - Muddy/ Saturated	3	51.4	3400	4621	5243	0.74	0.65
PCC Street	4	46.7	2700	4198	4763	0.64	0.57
PCC Street	5	49.8	2600	4477	5080	0.58	0.51

Notes: Weights of sand are from laboratory tests on samples obtained during field testing – 89.5 PCF is average uncompacted, and 102.0 PCF is average of compacted samples to approximately 88% Standard Proctor.
PCF = Pounds per Cubic Foot
PCC = Portland Concrete Cement

Table 5: Summary of Factor of Safety Calculations for Water 3' High Against 3' x 3' x 4' High Baskets

	Forces Resisting Sliding				Force Causing Sliding	
Test Surface	**Basket Weight** (γ_s x ~~V)~~	F_{Uplift} (γ_w x H x w^2/2)	μ	F_R	F_w (γ_w x H^2 x w)/2	**Factor of Safety**
	(lbs)	(lbs)		(lbs)	(lbs)	
Grass	4387	842	0.58	2056	842	2.44
Grass - Muddy	3956	842	0.78	2429	842	2.88
Grass - Muddy/Saturated	4621	842	0.70	2645	842	3.14
PCC Street	4338	842	0.58	2028	842	2.40

Table 6: Summary of Factor of Safety Calculations for Water 4' High Against 3' x 3' x 4' High Baskets

	Forces Resisting Sliding				Force Causing Sliding	
Test Surface	**Basket Weight** (γ_s x ~~V)~~	F_{Uplift} (γ_w x H x w^2/2)	μ	F_R	F_w (γ_w x H^2 x w)/2	**Factor of Safety**
	(lbs)	(lbs)		(lbs)	(lbs)	
Grass	4387	1123	0.58	1893	1497	1.26
Grass - Muddy	3956	1123	0.78	2209	1497	1.47
Grass - Muddy/Saturated	4621	1123	0.70	2449	1497	1.63
PCC Street	4338	1123	0.58	1865	1497	1.24

1) Summary of Calculated Friction Coefficient Data

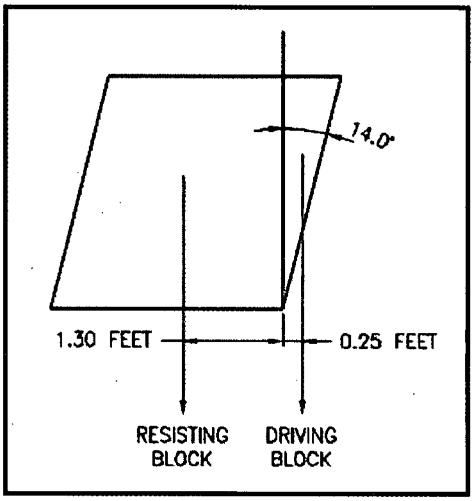
Friction coefficients were calculated for each of the field tests performed.

The field data showed significantly higher friction coefficients than the original engineering calculations, which used published friction coefficients for the different base materials. This is believed to be due to the deformation of the bottom edge of the basket, which was observed as it began to slide. This deformation cannot be discounted, however, as it would occur in the event that the lateral loads applied to the basket were enough to cause lateral movement. Therefore, the field measured friction coefficients are believed to be valid for the specific situations in which the baskets were tested.

These higher friction coefficients, in turn, show that the actual performance of the Hesco units in resisting sliding is higher than the calculated resistance using published friction coefficients, as shown by the factors of safety calculated in Tables 5 and 6.

5.2 OVERTURNING/TIPPING

Traditional methods of overturning analysis are not truly applicable for this type of container because of the general deformability of the system, plus the possibility that uplift pore-water pressures can often be dissipated through the sandy infill material. Even if a layer of sand is frozen at the base of the Hesco Concertainer, enough pore-water pressure would be likely dissipated so as to minimize or negate the uplift pressures, simply based on the fact that the drainage path is no longer than about 3 feet.



Therefore, the overturning and tipping will most likely be related to either 1) installation issues (where infill material is placed in a manner such that initial container tilt occurs), or 2) thaw of the subsoil on only one side of the container occurs, such that some differential settlement occurs (e.g., rising water on one side of barrier thaws the soil beneath one side).

As discussed earlier in this report, some of the units were experiencing some tilt, with angles nearing 6 or 7 degrees. Based on information obtained during the field work, it is believed that the units showing some tilt were either installed that way, or settlement of the units into the base soils occurred.

For a single layer system, a tilt of less than 14 degrees is a reasonable maximum value. The reason for this is because the system tends to operate as a block. Therefore, at an angle of 14 degrees or less, there is at least 7 times the mass holding back the container from tipping. When considering this angle, the resisting mass and the associated moment arm of the units, based on the resisting and driving forces, a calculated system factor of safety against overturning is greater than 30. This is shown by Equation 2 below. Overturning or tipping is not considered to be a significant problem, therefore, unless the entire subgrade fails.

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

$$FS = \frac{\text{Resisting Block Area} \times \text{Resisting Moment Arm} \times \text{Density}}{\text{Driving Block Area} \times \text{Driving Moment Arm} \times \text{Density}} \qquad \text{(Equation 2)}$$

5.3 SEEPAGE

Field personnel's input on the issue of seepage by the Hesco barriers varied greatly. Some thought that the seepage was excessive, while others thought it was less than a traditional sandbag levee would be. Most areas had poly-sheeting placed on the wet side of the Hesco units. However, an area of Drain 27 did not receive poly-sheeting, and the field staff thought that the seepage wasn't excessive and was easily managed.

Assessment of actual seepage rates in the field were not part of this report.

5.3.1 Review of Available Information

In 2004, the USACOE conducted tests on Hesco units in regards to seepage rates. These initial tests showed higher seepage rates than other levee systems. Most of the seepage occurred through the seams between adjacent units. Hesco learned after these test that the end panels on adjacent units should be removed to decrease the amount of seepage. Retesting of the units for seepage rates was conducted by USACOE in July and August, 2005. In this retest, the end panels of units butted up against on another were removed. This allowed for a continuously filled sand unit with no gaps between units. This retest showed seepage rates of 0.04 gpm/ft at 1' of head, and 0.14 gpm/ft and a head of 2.85'

6.0 Summary and Recommendations

Overall, the consensus of opinion among users of the Hesco barriers for the Fargo floodfight is that the barriers are well-designed, and were vital to the success of the effort to contain the flooding from the Red River of the North. They were appreciative of the speed of deployment (vital in emergency situations such as this), their ability to adapt to irregular subgrades, and the uniformity of results compared to sandbag dikes. Some cautions oftentimes repeated were to be careful with proper filling of the barriers, and to pay particular attention to the subgrade the barriers are placed on, as this can cause significant problems. Additionally, transitions between Hesco's and other types of dikes need to be done carefully, allowing an adequate overlap to prevent a weak spot in the resulting dike. Adequate monitoring of the completed barrier wall must be done, just as for any temporary dike, throughout the emergency period. Most users, especially those who used them in the field, declared they would use them again, given the same situation.

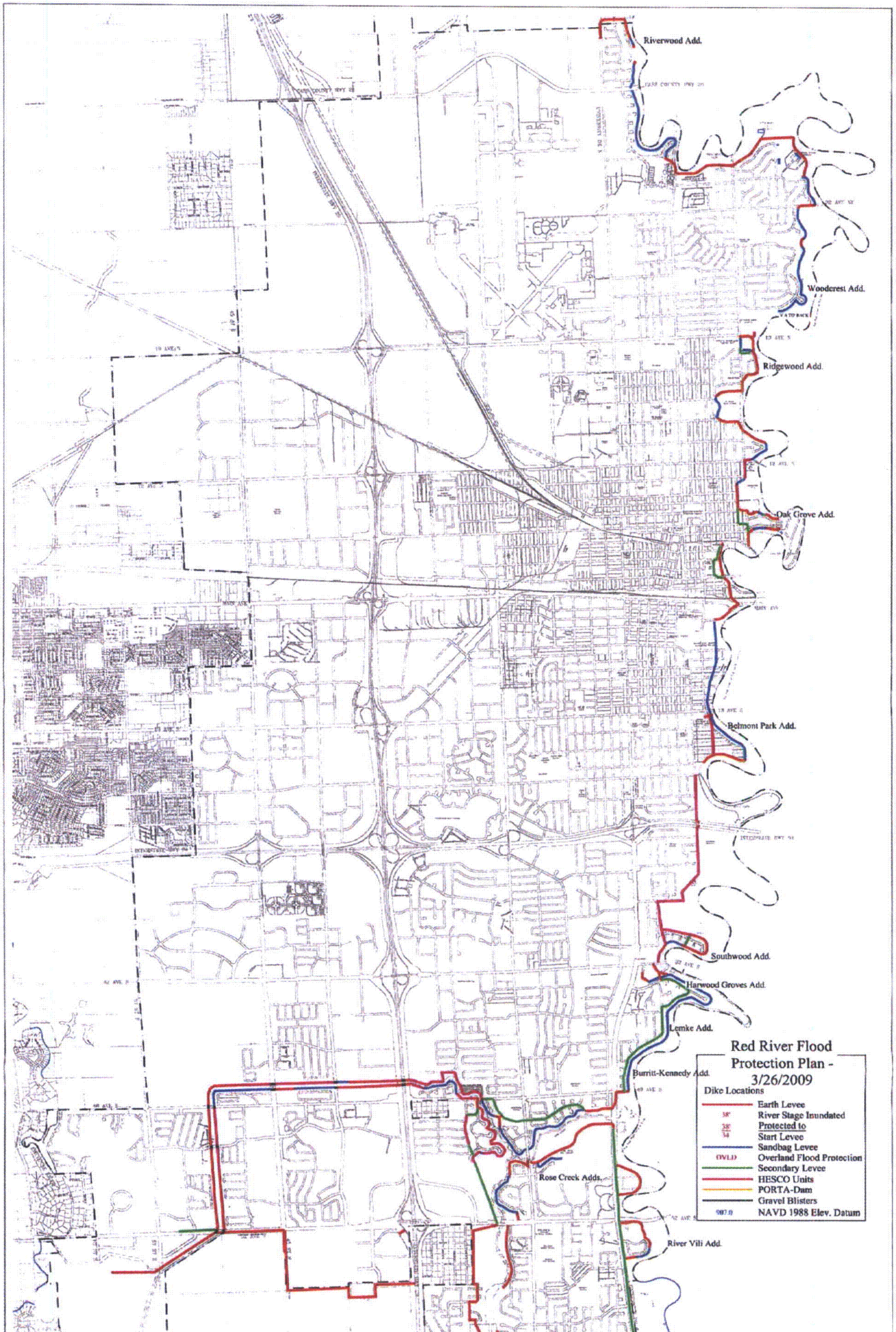
Some useful recommendations were made, however, and should be considered by Hesco Bastion.

- Consider use of **colored** hinge pins to join the units together. This would make the visual inspection of finished units easier and faster, particularly at night (i.e., Were the baskets properly joined during installation?).
- Additional training. Several users reported receiving only very minimal training in how to properly install the units. This caused considerable problems and delays in getting the various installations properly started, especially as new workers arrived to help.

- Preparation of a Guidance Document for communities considering using the Hesco barriers. Like most products being considered to fight a flood, proper engineering needs to be done prior to installing them. Such a guidance document could be given to communities prior to their using Hesco's, recommending the type of engineering needed, the considerations that need to be made, and procedures to follow for such things as needed site preparation, height of barriers needed for the predicted flood elevations and their configuration (e.g., 2-4' barriers with 1-4' stacked over them, or 2-4' with 2 more 4' barriers stacked over them), lessening seepage with plastic sheeting and how to do it (front face of barrier, back face, how anchored, etc.), joining Hesco barrier walls to sandbag or clay dikes (necessary overlap, tie-ins, etc.), and proper installation procedures.

Attachment A

Red River Flood Protection Plan – 3/26/2009
(Map of Levee System)


Red River Flood Protection Plan - 3/26/2009
Dike Locations
Earth Levee
38'
River Stage Inundated
38'
34'
Protected to
Start Levee
Sandbag Levee
OVLD
Overland Flood Protection
Secondary Levee
HESCO Units
PORTA-Dam
Gravel Blisters
987.0
NAVD 1988 Elev. Datum
Riverwood Add.
Woodcrest Add.
Ridgewood Add.
Oak Grove Add.
Belmont Park Add.
Southwood Add.
Harwood Groves Add.
Lemke Add.
Burritt-Kennedy Add.
Rose Creek Adds.
River Vili Add.
INTERSTATE HWY 94

Attachment B

"Engineering Analysis" from Report to: United States Senate Committee on Appropriations, June 29 – 30, 2004

Pages 1 and 2 are not included as part of this excerpted document

ENGINEERING ANALYSIS

The ability of the Concertainer® structure to withstand hydrostatic and uplift forces, as well as other forces, results primarily from a combination of shape and weight of the structure and the frictional resistance generated along its base. The linkages between the units also allows for the load on a single unit to be distributed over several adjacent units. The structure is compliant and deforms slightly as a response to applied loads. This particularly important when the structure responds to uplifting forces. The Concertainer® basket is basically a shell and will experience almost no uplifting forces. Since the basket is open at the bottom, if the unit is raised the fill material remains in contact with the ground surface. The uplifting force on the fill will be due to buoyancy and not from any mechanical force of the basket. Therefore, the conventional analysis of stability based upon overturning is not applicable to the Concertainer® structure. However, because the basket and fill could be displaced laterally, the analysis of the stability of the structure to sliding is appropriate.

The ability of the structure to resist lateral forces it can be theoretically analyzed based upon the assumption that the structure will respond as a rigid body to hydrodynamic forces. A general load case is shown in Figure 1.

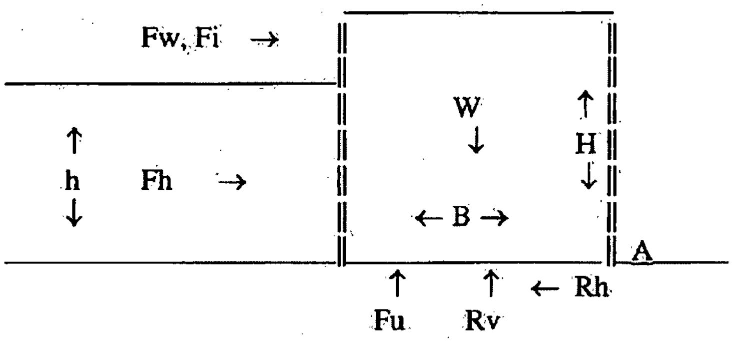


Figure 1. Schematic diagram of forces on a Concertainer® unit.

The Figure illustrates that the force per foot of structure on the Concertainer® can result from several sources:

W = weight of the basket and fill
Fh = hydrostatic pressure force
Fw = wave forces
Fi = impact force
Fu = uplift force
Rv = vertical reaction force of the soil
Rh = horizontal reaction force of the soil, with a maximum value equal to Cf Rv, where Cf is the coefficient of friction along the interface

The formulas for the static forces for the load case shown in Figure 1 and their lines of action from point A, are as follows:

$W = \frac{1}{2} \gamma_{fill} B H$	@ B/2
$Fh = \frac{1}{2} \gamma h^2$	@ h/3
$Fu = \frac{1}{2} \gamma B h$	@ 2/3 B
$Rv = W - Fu$	@ 1/3 B
Rh = Fh with maximum value of Cf Rv	

Where:

B = width of the Concertainer®
H = height of the Concertainer®
γ_{fill} = unit weight of the fill or S γ
γ = unit weight of water
S = specific gravity of the fill
h = height of water above the base of the structure

The resistance to sliding can be expressed as a factor of safety, which is the ratio of the resisting forces to the applied forces. The horizontal resisting force is the frictional resistance generated along the base of the structure, given by Cf Rv. The applied hydrostatic force is Fh. Thus factor of safety against sliding can then be defined by

$$SF = Cf\,Rv/Fh = Cf(W\text{-}FU)/Fh$$

The analysis presented is based upon treating the structure as a rigid body, the Concertainer® is actually deformable and it would affect the impact loads and the overturning. The Concertainer® is highly resistant to impact loads because the basket and fill deform when the load is applied, thus lengthening the time over which the impacting object is stopped, and hence reducing the force. The amount of deformation would depend upon the where the impact occurred, with more deformation occurring near the top of the structure.

The Concertainer® structure is well suited to resist impact loads. The structure is compliant such that it will deform under loads. This property means that a unit will absorb debris loads and actually experience a lower force from debris than rigid structures would experience for the same debris. This can be explained because debris loads resulting from floating objects such as vegetation, logs and lumber are impact loads. In an impact load the force produced by the impacting object depends upon the initial momentum of the object, its mass time its velocity, and the time over which the objects velocity is reduced to zero by the impact; that is its deceleration. The compliancy of the structure thus extends the time over which the impacting object is stopped. This results in a reduced deceleration and hence a reduced force on the structure. The performance of the structure under debris loads would also depend upon the water depth relative to the top of the structure, the fill in the structure and the shape of the debris object. Impact tests for specific objects of interest for various fill types would need to be conducted. The effect of debris loads on the performance of the Concertainer® can be accounted for by including impact loads in the analysis of the factor of safety against sliding.

Waves can affect the Concertainer® structure in several different manners: as an additional horizontal force, as a carrier of debris, and as a mechanism for removing material from the structure. The effects of waves will depend upon whether the waves hitting the structure are non-breaking, breaking or broken waves. The horizontal force on a structure produced by each type of wave can be computed from standard coastal engineering design procedures, e.g., the Shore Protection Manual, and included in the analysis of the resistance of a structure to sliding for various unit sizes and types of fill. Debris loads could be severely increased under wave action. While the movement of water resulting from a current will be generally parallel to the structure, wave action causes water movement that is more generally perpendicular to the structure. The velocity of the water at the crest of a breaking wave approaches the phase speed of the wave and, even in shallow water, can reach a value of several feet/sec. Thus velocity of the debris could be greatly increased by the presence of waves. The property of the Concertainer® to absorb impact loads clearly becomes an advantage in resisting this wave enhanced threat from debris. The effect of waves on the erosion of material from the structure will depend upon the height of the mean water at the structure, the height and type of wave hitting the structure, and the fill material. When the combined mean water height and incoming wave height is lower than the top of the structure, no erosion would occur. For mean water levels below the top of the structure, but with wave height high enough to overtop the structure, erosion would be minimal. Water would be thrown onto the top of the fill with little horizontal velocity and wet the fill. For higher waves, waves that break into the structure, there would be some initial suspension and transport of fill out of the structure. When the mean water height exceeds the height of the structure so that it becomes submerged all types of waves would suspend some fill material. The amount of fill removed would depend upon the intensity of the wave action and the type of fill. These various effects of wave action on the structure would need to be considered in the selection of the Concertainer® size and fill so as to maintain an acceptable factor of safety against sliding under expected field conditions.

GROUND SURFACE PERFORMANCE

The performance of the Concertainer® on various surfaces will depend both on the type of surface and the type of fill used in the structure. This is because the same fill will interact differently with different surface materials. The net effect of the surface/fill interaction can be expressed through the interface friction coefficient. As shown above, the friction coefficient directly affects the resistance of the structure to sliding. Other factors that may need to be considered concerning the surface upon which the structure is placed are the permeability of the surface and it's bearing capacity. Given the test conditions described in the solicitation, the bearing capacity and permeability of the test surfaces should present no problems. However, in actual usage, these issues would need to be investigated at each field site.

The actual coefficient of friction between different fill materials and the different test surfaces will depend upon the detailed characteristics each. Since these are not known at this time, representation values of the friction coefficient can be taken from published values. The following values were used in the stability analysis:

Table 1. Soil parameters used in the analysis.

Fill Type	Specific Gravity	Interface Coefficient of Friction		
		Earth	Concrete	Grass
Fine Sand	1.60	.58	.35	.30
Coarse Sand	1.76	.67	.45	.35
Gravel	1.92	.78	.60	.40

The coefficients of friction between concrete and for various fill types are taken from the Shore Protection Manual (Table 7-15 and 7-16). Table 7-16 gives the friction coefficients for concrete dams on sand and gravel. For freshly graded surfaces, earthen material is present both in the container and on the surface. The friction resistance will depend upon the angle of internal friction for the each material. The values used in the analysis for the various fills on an earthen surface are based upon the angles of internal friction for firmly packed sediments as given in Table 7-15 of the SPM. For the grass surface case, the approach taken is that the coefficient of friction will be assumed to be smaller than for a concrete surface. Thus the concrete values were reduced for gravel, coarse sand, and fine sand by factor of .67, .77 and .86 respectively.

FIELD REPAIR AND MAINTENANCE

Depends on the location.

TEST CONDITION ANALYSIS

The performance of the Concertainer® under a particular set of test conditions can be determined using the formulas presented above. Various load cases were considered based upon the type of surface at the test site, the height of the floodwater, the size of the structure and the fill material. The results of these calculations are given in Table 2.

A single load case will be used to illustrate the methodology used in computing the factor of safety against sliding. The structure will be assumed to be placed on either grass, earth or concrete. A 3 foot by 3 foot unit will be subject to a 3 foot flood, with no waves or impact loads. The structure will be fill with either fine sand, coarse sand, or gravel. The formula for the factor of safety against sliding for a 3 foot Concertainer® unit (b=H=3 feet) as

$$FS = Cf\,(W-Fu)/Fh$$

or

$$FS = Cf\,(HBS\gamma-hB\gamma/2)/(h^2\gamma/2) = 2BCf\,(HS-h/2)/(h^2)$$

This can be simplified for H = B = 3 ft, and h=3 feet to

$$FS = .67\,Cf\,(3S - 1.5)$$

For the various fill materials and surface types the values of Cf and S can be specified. For example, for an earthen surface and with a fine sand fill, S= 1.60 and Cf = .58. The computed factor of safety is

$$FS = .67\,(.58)\,(3(1.60) - 1.5) = 1.28$$

This is the result shown in Table 2 for load case 1. For coarse sand S = 1.76 and Cf = .67, and the resulting factor of safety is 1.69, as shown in Table 2 for load case 2. For gravel, S = 1.92 and Cf = .78, and the factor of safety is 2.22, as shown in Table 2 as load case 3.

The other load cases listed in Table 2 were based upon changing the surface types, flood water depth and unit size. A second set of calculations were performed based upon increasing the flood water depth to 4 feet, and placing a 2 foot by 2 foot Concertainer® on top of a 3 foot by 3 foot unit. The factors of safety against sliding for different surfaces are given in load cases 28, 29 and 30.

Overall the analysis indicates that for the fill types and surface types considered, large changes in the factor of safety can occur. For example, for a 3 foot by 3 foot unit on a concrete surface the factor of safety changes from .77 to 1.13, to 1.70 as the fill is changed from fine sand, to coarse sand and then to gravel.

Table 2. Factor of safety against sliding for various load cases.

Load Case	Surface Type	Structure Hgt	Flood Hgt	Fill Type	Factor of Safety Against Sliding
1	E	3'	3'	FS	1.28
2	E	3'	3'	CS	1.69
3	E	3'	3'	GR	2.22
4	C	3'	3'	FS	.77
5	C	3'	3'	CS	1.13
6	C	3'	3'	GR	1.70
7	G	3'	3'	FS	.66
8	G	3'	3'	CS	.88
9	G	3'	3'	GR	1.14
10	E	4'	3'	FS	2.53
11	E	4'	3'	CS	3.30
12	E	4'	3'	GR	4.28
13	C	4'	3'	FS	1.52
14	C	4'	3'	CS	2.22
15	C	4'	3'	GR	3.29
16	G	4'	3'	FS	1.31
17	G	4'	3'	CS	1.72
18	G	4'	3'	GR	2.20
19	E	4'	4'	FS	1.28
20	E	4'	4'	CS	1.69
21	E	4'	4'	GR	2.22
22	C	4'	4'	FS	.77
23	C	4'	4'	CS	1.13
24	C	4'	4'	GR	1.70
25	G	4'	4'	FS	.66
26	G	4'	4'	CS	.88
27	G	4'	4'	GR	1.14
28	E	4'	5'	FS	1.07
29	E	4'	5'	CS	1.41
30	E	4'	5'	GR	1.85

Note: E = Earthen surface
C = Concrete surface
G = Grass surface
FS = Fine sand fill
CS = Coarse sand fill
GR = Gravel fill

The data presented herein by HESCO Bastion USA, LLC from the Rapid Deployment Flood Wall Testing at Engineering Research and Development Center (ERDC) Water Experimental Station (WES) in preliminary information from Dr. Joseph Suhayda.

HESCO Bastion USA, Inc.
47152 Conrad E. Anderson Drive
Hammond, LA 70401

Tel: 985-345-7332
Email: info@hesco-usa.com
Web: www.hesco-usa.com

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