ENGINEERING REPORT

EMBANKMENT PROTECTION ANALYSIS

HOUSATONIC RIVER and NAUGATUCK RIVER FLOOD PROTECTION PROJECTS

SECTION 1

ANSONIA and DERBY, CONNECTICUT

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MMI #1560-119 and #3118-03

Prepared for:

City of Ansonia
253 Main Street
Ansonia, CT 06401

City of Derby
One Elizabeth Street
Derby, CT 06418

Prepared by:

MILONE & MACBROOM
99 Realty Drive / Cheshire, Connecticut 06410
203.271.1773 / 203.272.9733 (Fax)
www.miloneandmacbroom.com

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1.0 PROJECT DESCRIPTION

In June 2010, Ansonia and Derby retained MMI of Cheshire, Connecticut to perform the investigative and engineering services required to evaluate and certify the Housatonic River and Naugatuck River Flood Control Systems in support of the municipalities' request to obtain accreditation from FEMA. The descriptions and supporting documentation included in this report were performed only for Section 1 of the Flood Control Systems which is explained and graphically depicted on Figure 1:

- Section 1 – The left (east) bank of the Housatonic River in Derby from Bridge Street to the confluence with the Naugatuck River/Route 8 embankment and the right (west) bank of the Naugatuck River from the Main Street (Route 34) bridge north through Derby to the embankment supporting Pershing Drive in Ansonia.

1.1 Federal Regulatory Criteria

In order to establish and/or maintain accreditation of a levee system, the City of Ansonia and the City of Derby are required to demonstrate compliance with Section 65.10 under Title 44, Chapter 1, Subchapter B, Part 65 of the Code of Federal Regulations. For the purposes of this report, Milone & MacBroom, Inc. (MMI) performed an analysis of the levee embankment protection in accordance with Section 65.10(b)(3) of the NFIP, "Embankment Protection." which is provided below.

§ 65.10 Mapping of Areas Protected by Levee Systems

(3) ***Embankment protection.***

Engineering analyses must be submitted that demonstrate that no appreciable erosion of the levee embankment can be expected during the base flood, as a result of either currents or waves, and that anticipated erosion will not result in failure of the levee embankment or foundation directly or indirectly through reduction of the seepage path and subsequent instability. The factors to be addressed in such analyses include, but are not limited to: Expected flow *velocities (especially in constricted areas); expected wind and wave action; ice loading; impact of debris; slope protection techniques; duration of flooding at various stages and velocities; embankment and foundation materials; levee alignment, bends, and transitions; and levee side slopes.*

2.0 EXISTING CONDITIONS

The system of dikes and walls extends from the north bank of the Housatonic River south of the Bridge Street bridge in Derby to the west bank of the Naugatuck River and Pershing Drive roadway embankment north of the Metro-North railroad bridge in Ansonia. The flood protection levee system is approximately 2.15 miles long extending approximately 1.55 miles in Derby and 0.6 miles in Ansonia.

The protection along the Housatonic River starts with a 350-foot long floodwall south of the Bridge Street bridge, joining with an earthen dike and continuing about 1,350 feet downstream. The levee ties into the CT Route 8 embankment near the Route 8 bridge over the Housatonic River. The Route 8 embankment serves as a dike linking the downstream end of the dike along the Housatonic River with the downstream end of the dike along the Naugatuck River. The dike/levee system continues upstream along the west bank of the Naugatuck River as an earthen dike starting at Main Street (CT Route 34), crossing Division Street, and ending just north of the Metro-North railroad bridge in Ansonia.

Riprap lining protection is found along the riverward slopes of the levee embankment in Derby and Ansonia. Also, stone riprap protects the fill along the riverside bottom of the floodwall downstream of the Bridge Street bridge and the south end slope of the CT Route 8 embankment. The section of the levee system along the CT Route 8 embankment is not covered with stone riprap but is protected with a stable impervious soil blanket over the rock fill embankment, which protects the embankment during base flood conditions.

3.0 EVALUATION OF THE CT ROUTE 8 EMBANKMENT

The highway embankment for Route 8 was constructed with an impervious soil blanket that protects the rock fill embankment during base flood conditions. Historically, this area has not been effectively maintained to prevent the growth of invasive species of trees and shrubs. In accordance with the Operations and Maintenance requirements for this area and in order to determine the conditions of the existing impervious soil blanket and the stability of the embankment, the City of Derby has initiated removal of the woody vegetation, which to date has included the stump removal for 10 of the larger species of trees and shrubs along the embankment.

On November 10, 2001, the City of Derby DPW staff, observed by MMI engineers, removed the root structure and exposed the subsurface soil conditions and the impermeable soil blanket layer. In each location, the removed root structure was found to be very shallow with a maximum depth of 12 inches to 18 inches. Little or no intrusion into the impervious soil blanket originally installed by the U.S. Army Corps of Engineers (USACE) was found. In addition, it was observed that aside from the invasive knotweed and a few other deciduous and evergreen species most of the vegetation along the embankment consists of a small invasive species known as "Russian olive." Some of the larger Russian olive shrubs were removed and found to have very shallow roots, approximately 12 inches deep.

Based upon the limits of inundation expected during the base flood, which are shown on a map attached to this report, and the findings during the tree and shrub removal effort, it is our opinion that the existing impervious soil blanket protection has not been compromised by the overgrown vegetation and, therefore, should provide the intended protection during base flood conditions. The City of Derby continues to work on the removal of the vegetation as staff is available. It is expected that the removal of the woody vegetation and stump will be completed in spring 2011.

4.0 STONE RIPRAP SLOPE PROTECTION

4.1 General

The riprap protection was originally designed and placed by the USACE as part of both the Derby and Ansonia Local Flood Protection Projects. The design details of the stone revetment can be found in the USACE Design Memorandum No. 3, "Hydraulic Analysis and Riprap Design," prepared in April 1968 for the Derby Local Protection Project as well as in the USACE Design Memorandum No. 6, "Embankments, Foundations and Channel Improvements," which was prepared for the Ansonia – Derby Local Protection Project in 1966. Both memorandums were reviewed prior to evaluating the existing riprap lining protection.

Another source of information that was used for evaluating the riprap size along the Naugatuck River is the report prepared in the 1960s by Howard, Needles, Tammen and Bergendoff, "Determination of Stream Encroachment Lines" for the Naugatuck River through the towns of Derby and Ansonia. This report was then compared to the published FEMA Flood Insurance Study (FIS) as well as the USACE memorandums, and the most conservative data was utilized during the evaluation process. MMI took a conservative approach due to the variety of sources of information and design data found during the review of the available design reports. The computations included in this report were supported with a visual inspection of the embankment and confirmed with sizing measurements of the existing riprap stone.

4.2 Methodology

For this analysis, the size of the existing stone riprap placed along the riverside of the levee embankment was evaluated using both the permissible velocity and tractive force approaches. Both methods determine the mean riprap size (also known as D_{50}) based on the depth of flow, velocities in the channel, embankment side slopes, and channel bed slope.

4.2.1 Permissible Velocity Approach: Permissible velocity procedures are empirical in nature where the channel can be considered stable if the adopted velocity is lower than the maximum permissible velocity for the given channel boundary condition. The equation for computing the D_{50} based on the velocity is:

$$D_{50} = 0.001\ Va^3 / (d_{avg}^{\ 0.5}\ K_1^{\ 1.5})$$

where: D_{50} = mean riprap size (feet)

Va = velocity adopted in the channel (feet/second)

d_{avg} = average flow depth (feet)

$$K_1 = (1-(\sin^2 \Theta / \sin^2 \Phi))^{0.5}$$

where: Θ = bank angle with the horizontal

Φ = riprap material's angle of repose

The equation is based on a stone riprap specific gravity of 2.65 and stability factor of 1.2. The stability factor is used to increase the design riprap size to reflect uncertain factors such as the effect of debris or ice jams and the forces from wind-generated waves. Therefore, a correction factor based on the riprap specific gravity and the stability factor is computed and added to the design of the riprap size.

4.2.2 Shear Stress Approach**:** The tractive force method (shear stress) considers actual physical processes occurring at the channel boundary, thus representing a more realistic model of the erosion process. The hydrodynamic force created by water flowing in a channel causes a shear stress on the channel lining materials. The bedding material, in turn, resists this shear stress by developing a tractive force. Tractive force theory states that the flow-induced shear stress should not produce a force greater than the tractive resisting force of the bedding material. This resisting force creates the permissible or critical shear stress of the bedding material. The critical shear stress in a channel defines the force required to initiate the movement of the channel bed or lining material. If the shear stress equals the critical shear stress, the channel or the lining material will likely be in equilibrium. The average shear stress is defined by:

$$\tau = \gamma R S$$

where: τ = average shear stress (lb / ft^2)

γ = unit weight of water (62.4 lb/ft^3)

R = hydraulic radius, or depth of flow (feet)

S = energy slope, or average bed slope (ft/ft)

$$\tau = \tau_p = 5 D_{50}$$

where: τ_p = permissible shear stress (lb / ft^2)

The computations for the minimum D_{50} required for the riverside slope along the embankment of both the Naugatuck River and Housatonic River are included in this report. The D_{50} for the Naugatuck River was determined to be ±0.5 foot which is the gradation of an intermediate riprap size. Similarly, the computations determined a minimum D_{50} for the stone revetment along the Housatonic equivalent to a standard riprap size. This analysis used the Connecticut Department of Transportation (ConnDOT) standard gradations as a guideline which is defined as:

Riprap Type	**D_{50} (feet)**
Modified	< 0.42
Intermediate	$0.42 < D_{50} < 0.67$
Standard	$0.67 < D_{50} < 1.25$

The computed D_{50} was then compared to the actual stone revetment placed along the dike. The riprap was measured and visually inspected which confirmed that not only the size of the existing stone riprap for both rivers is adequate, but it exceeds the required D_{50} and it is installed with appropriate depth along a stable slope. Therefore, we concluded that the existing stone revetment provides adequate protection for the riverside embankment of the levee. Photos have been included along with the supporting computations for further evaluation.

5.0 ANALYSIS OF EROSION POTENTIAL

Based on the computations performed using the design criteria described above, the stone revetment along the riverward slopes of the levee was confirmed to be the appropriate size, installed to a depth and constructed to a slope that will continue to prevent erosion of the levee embankment during base flood conditions. This conclusion was supported with visual inspections and field measurements of the riprap rock.

A Geotechnical Evaluation Report prepared by Paulus, Sokolowski and Sartor Architecture and Engineering (PS&S) in December 2010 provided a detailed analysis of the embankment stability, settlement, and seepage. This report is included as part of the recertification package of the existing levee and is available for further evaluation. The results of the geotechnical report support the finding that the embankment and foundation materials provide adequate support for the revetment. The scour protection analysis performed by MMI indicates that the existing riprap armoring provides adequate erosion protection during the base flood event.

The levee generally follows a linear alignment with the exception of the area immediately downstream of the Metro-North railroad track in Ansonia. A bend in the alignment of the Naugatuck River occurs in this area to convey the river under the railroad bridge. Large cut blocks of granite were machine placed along both sides of the riverbank and adjacent to the railroad abutments. Based upon flow velocities and required intermediate riprap protection for this section of the levee, the granite revetment far exceeds the required size to maintain the stability of the bank during the base flood.

The limits of inundation during the base flood are well within the limits of the channel constructed by the USACE including the required freeboard. Structures within the base flood elevation that would be exposed to debris include the piers and abutments of the railroad and street bridges as well as the sluice gate structures located along the course of both the Housatonic and Naugatuck Rivers. Damage to these structures caused by debris is expected to be minimal and should not diminish the overall ability of the flood control system. This was confirmed with field inspections by MMI engineers of these structures that showed them to be in good working order. In addition, the sluice gate structures area is accessed by bridges from the top of the levee embankment. The bottom of the access bridge to each sluice gate is at or above the water surface elevations during the base flood.

The normal river depth along both the Housatonic River and Naugatuck River upstream from their confluence is relatively shallow and influenced by the tidal fluctuations of Long Island Sound. Therefore, the potential for ice jams or loading due to significant ice accumulation is limited and not expected to adversely impact the conveyance of the base flood. In addition, the analysis of the riprap size along the embankment included a correction factor that takes into account uncertain hydraulic factors such as these and increases the required riprap size.

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SUPPORTING DOCUMENTATION