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Analysis of INDOT Current Hydraulic Policies

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JOINT TRANSPORTATION RESEARCH PROGRAM
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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract
Hydraulic design often tends to be on a conservative side for safety reasons. Hydraulic structures are typically oversized with the goal being reduced future maintenance costs, and to reduce the risk of property owner complaints. This approach leads to a conservative design with higher construction costs. Therefore, there is a need to quantify the cost-benefit aspect of this conservative approach. Accordingly, the overall objective of this project is to compare hydraulic design policies of Indiana Department of Transportation (INDOT) with that of other states, and perform cost-benefit analysis of large versus smaller hydraulic structures in terms of capital and maintenance costs. Comparison of INDOT's culvert design is similar to that of Michigan, and is most updated compared to Ohio, Illinois and Kentucky. INDOT uses Q_{100} as the design discharge, which is conservative compared to other neighboring states that use Q_{50} as the design discharge for designing culverts. By using the data from 16 culvert design examples including both new-alignment and replacement structures, cost benefit analysis is performed in the light of suggested revision in culvert hydraulics policy. Results show that an increase in backwater limit to 1' will result in 44% reduction in culvert size (represented as culvert area) with an average backwater of 0.79'. Increase in backwater limit will also increase the outlet velocity by 72% that may result into extra cost in outlet protection structures. Depending on the type and the size of the culvert, a change in hydraulic policy may result in saving from 12 -58% of the original cost associated with the current conservative design.

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EXECUTIVE SUMMARY

PROJECT MANAGEMENT TRAINING

Introduction

Hydraulic design often tends to be on a conservative side for safety reasons. Hydraulic structures are typically oversized, with the goal being reduced future maintenance costs and reduced risk of property owner complaints. This approach leads to a conservative design with higher construction costs. Therefore, there is a need to quantify the cost-benefit aspect of this conservative approach. Accordingly, this project has the following three objectives:

(i) Compare design policies of INDOT with those of border states (Ohio, Illinois, Michigan, and Kentucky); (ii) Perform cost-benefit analysis of large versus smaller hydraulic structures in terms of capital and maintenance costs; and (iii) Investigate ways to improve the hydraulic design by looking at the effect of input data and sources.

Findings

- In general, the hydrologic design policies implemented by Indiana (INDOT) and Michigan are most updated compared to Ohio, Illinois, and Kentucky design policies. For example, INDOT uses TR20 and HEC1 software programs for computing design discharge, whereas Illinois hydrologic policy recommends the use of USGS regression equations.
- The magnitude of INDOT design discharge (Q_{100}) is conservative in comparison to Illinois and Kentucky design discharge (Q_{50} or less). The magnitude of design discharge for Michigan and Ohio is similar to that for Indiana.
- INDOT's culvert design discharge magnitude (Q100) is conservative in comparison to other states' culvert design discharge magnitudes. For example, Illinois uses Q50 as design discharge compared to Q100 by Indiana.
- INDOT's maximum back water limit criterion (1.5") for new alignment culverts is not found in neighboring states' design manual. The maximum back water limit criterion becomes limit criterion for culvert design (culvert size) in many cases.
- An increase in backwater limit to 1' will result in 44% reduction in culvert size (represented as culvert area) with an average backwater of 0.79'. Increase in backwater limit will also increase the outlet velocity by 72% that may result into extra cost in outlet protection structures.
- Depending on the type and the size of the culvert, a change in hydraulic policy may result in saving from 12 to 58% of the original cost associated with the current conservative design.

Implementation

The hydraulics division at INDOT will use the findings from the final project report in determining the modifications to the current hydraulics design policies.

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INTRODUCTION

Hydraulics plays a major role in highway engineering to collect, transport, and dispose surface water originating on or near the highway right-of-way, to handle river and other water crossings, and to handle subsurface water conditions. Hydraulic or drainage design is a unique field of Civil Engineering, because most often it relies on empirical equations, judgment, experience, and common sense to find answers to engineering questions. The hydraulic engineering judgments or decisions are guided by drainage design methodologies. Therefore, the drainage designer must fully understand each method that is employed, including its limitations. Because of this empirical approach, hydraulic designs tend to be on a conservative side for safety reasons. Hydraulic structures are typically oversized to reduce future maintenance costs the risk of property owner complaints. This approach leads to conservative design with higher construction costs. Therefore, there is a need to quantify the cost-benefit aspect of this conservative approach. There is a need to quantify the trade-off between conservative design versus maintenance and legal costs due to complaints/lawsuits from property owners. In addition, the INDOT Production Management Division has been asked to provide suggestions for reducing construction costs. Studying culvert sizing policies to determine situations for making less conservative design would be a good starting point in reducing the overall construction costs. Accordingly, this project has the following three objectives:

1. Compare design policies of INDOT with those of border states (Ohio, Illinois, Michigan, and Kentucky).
2. Perform cost-benefit analysis of large versus smaller hydraulic structures in terms of capital and maintenance costs.
3. Investigate ways to improve the hydraulic design by looking at the effect of input data and sources.

Description of the project task related to each objective is presented in the following sections.

TASK 1: COMPARATIVE ANALYSIS OF DESIGN POLICIES AND PROCEDURES

1.1 Hydrologic Policy Comparison

This task compared INDOT hydrologic policies for culvert and bridge design (Chapters 29, 31, and 32) with design policies from neighboring states including Illinois, Michigan, Ohio, and Kentucky. A comparison of design discharge calculation methods and magnitudes are shown in Tables 1.1 and 1.2, respectively. Major findings from this task are:

(1) In general, the hydrologic design policies implemented by Indiana (INDOT) and Michigan are most updated compared to Ohio, Illinois, and Kentucky design policies. For example, INDOT uses TR20 and HEC1 software programs for computing design discharge, whereas Illinois hydrologic policy recommends the use of USGS regression equations.

(2) The magnitude of INDOT design discharge (Q100) is conservative in comparison to Illinois and Kentucky design discharge (Q50 or less). The magnitude of design discharge for Michigan and Ohio is similar to that for Indiana (Table 1.2).

1.2 Culvert Design Policy Comparison

A comparison of culvert design policy for all 5 states (IN, IL, OH, MI, and KY) is presented in Table 1.3. Major findings from this comparison are:

TABLE 1.1
Comparison of Design Discharge Calculation Method

Sl. No.	Facility/Structure	Preference 1	Preference 2	Only for Preliminary Investigation
INDIANA (Indiana, 2011)				
1	Stream flow, Bridges, and large Culverts	INDR Coordinated Curve	TR 20, HEC1	USGS Regression Equations
2	Small Culverts	TR20, HEC1	Rational method	USGS Regression Equations
3	Storm Drain, Roadside Culverts, Inlet Spacing	Rational Method (for < 200 acres in rural area)	TR 20, HEC1	
ILLINOIS (Illinois, 2011)				
1	Bridges, Culverts, and Channel	USGS Regression Equations	TR20, HEC1	
MICHIGAN (Michigan, 2011)				
1	DA> 2 Sq. Miles	MDEQ - SCS, regression, and Runoff Models		
2	20 Acres < DA < 2 Sq. Miles	MDEQ-SCS		
3	DA < 20 Acres	Rational Method		
OHIO (Ohio, 2011)				
1	DA> 6 Acres	USGS Regression Equations		
2	DA < 6 Acres	Rational Method		
KENTUCKY (Kentucky, 2011)				
1	DA > 1000 Sq. Miles	USGS Regression Equations (Food in Kentucky method)		
2	200 Acres < DA < 1000 sq. miles	USGS Regression Equations (Regional method)		
3	DA < 200 Acres	Rational Method		

(Note: DA represents Drainage Area)

TABLE 1.2
Comparison of Design Discharge

INDIANA					
Sl. No.	Highway Classification	Bridge water way opening		Roadway Cross Culverts	
		Allowable backwater	Allowable velocity	Allowable backwater	Allowable velocity
1	Freeways	Q100	Q100	Q100	Q50
2	Multilane Non-Freeways	Q100	Q100	Q100	Q50
3	Two lane Facility*				
3a	AADT ≥ 3000	Q100	Q100	Q100	Q50
3b	3000 > AADT > 1000	Q100	Q100	Q100	Q25
3c	AADT < 1000	Q100	Q100	Q100	Q10
* Traffic volume are for a 20-year projection					
ILLINOIS					
Sl. No.	Facility	Rural highways	Urban highways		
			All highway except TWS-2 with DHV <1250	TWS-2 with DHV < 1250	
1	Bridges and Culverts	Q50	Q50	Q30	

Note: TWS-2: Two way street, 2 Lane

TABLE 1.2
Comparison of Design Discharge (Cont'd)

MICHIGAN			
Sl. No.	Facility		Design discharge
1	All Highways Encroaching on the floodplain		Q100
OHIO			
Sl. No.	Facility		Design discharge
1	All Highways Encroaching on the floodplain		Q100
2	Flood Clearance		
2a	Freeways or other multi-lane facilities with limited or controlled access		Q50
2b	Other highways (2000 ADT and over) and Freeway Ramps		Q25
2c	Other highways (under 2000 ADT)		Q10
KENTUCKY*			
Sl. No.	Facility	Traffic Volume	Design discharge
1	Bridges	ADT < 400	Q10
		400 < ADT < 1500	Q25
		1500 < ADT	Q50
2	Culverts	ADT < 400	Q10
		400 < ADT < 1500	Q25
		1500 < ADT	Q25

Kentucky drainage manual is being updated and the updated version is not yet available

TABLE 1.3
Comparison of Culvert Design Policy

Sl. No.	**Group**	**Subgroup**	**IN**	**IL**	**MI**	**OH**	**KY**	**Remarks**
1	Design Discharge		Q100	Q50	Q50 for design and Q100 for check	Q50 for design and Q100 for check due to flood hazard	Q25	Analyze the mean life span of the culvert and find out whether Q50 or Q100 is more suitable
2	Maximum Backwater / Allowable Head Water (AHW)	Maximum backwater Edge of pavement elevation	1.5" Two feet below for Q100	a) pavement elevation b) prevent damage to upstream properties	a) 1.5 feet below edge of shoulder b) no greater than elevation of flow diverts	Two feet below the low edge of pavement for DA >= 1000 acres and one feet for DA < 1000 acres	a) based on sound judgment b) use Q500 for Nuclear Power Plants, Q100 for houses, and Q25 for farmland and barrens	1.5" backwater becomes main limiting criteria for AHW

TABLE 1.3
Comparison of Culvert Design Policy (Cont'd)

Sl. No	Group	Subgroup	IN	IL	OH	MI	KY	Remarks
3	Cover	For circular pipe	cover > 1'	minimum 6" for circular pipe	Adequate cover	a) For corrugated steel and aluminum box culverts and corrugated steel long span culverts: cover > 18"	a) Minimum cover : 1 ft, but 2 ft is desirable	may be 100 ft is misprint, it should be 10 ft
			cover < 100'			b) For PRC Arc Section: 1'<cover<12'	b) Maximum cover: 120 ft for circular pipe, and 15' for non-circular pipe	
		for deformed corrugated interior pipe material	cover > 1.5' cover < 13'	No cover for Box culverts		c) For other PRC box culverts and three sided flat top culverts: cover < 10 or 8' depending upon the span length		

TABLE 1.3
Culvert Design Policy Comparison (Cont'd)

Sl. No	Group	IN	IL	OH	MI	KY	Remarks
4	Maximum Outlet Velocity (Vo)	a) Revetment riprap for Vo < 6.5 ft/s b) Class 1 riprap for 6.5 ft/s < Vo < 10 ft/s	1) Rule of thumb: Vo < 10 ft/s 2) should be based on amount of sediment in the flow or abrasive potential to the culvert	a) For Vo < 6 ft/s : no special treatment b) for higher velocity erosion control structure is required	a) For Vo < 5 ft/s: no protection b) For 5ft/s < Vo < 20 ft/s: Rock channel protection,	Not Found	
		c) Class 2 riprap for 10 ft/s < Vo < 13 ft/s, 4) energy dissipater for Vo > = 13 ft/s	3) culvert manufacturer specification		c) For Vo > 20 ft/s: Energy dissipater		

TABLE 1.4
Main features of INDOT's bridge design policy

Sl. No.	Group	Subgroup	IN
1	Design Strom Frequency	Allowable backwater	Q100
		Roadway Serviceability, Note 1	Q100/Q25/Q10, Note 2
		Allowable Velocity	Q100
2	design program		WSPRO and HEC-2
3	Back water		IDNR or INDOT criteria, backwater should not exceed 1.5", Note 3
4	free board		minimum 2-ft for passage of ice and debris
5	Bridge Sizing	a. does not require IDNR permit	
		b. does require IDNR permit	DA > 50 mi2 in rural area and DA > 1 mi2 in urban area
6	Span length	for bridge > 3 spans	minimum span length should be > 100 ft for the spans over the main channel
		for bridge of 3 spans	central span length should be maximized
		for bridge of 2 spans	subject to approval of hydraulic engineer
7	Scour Depth	for bridge foundation	Maximum scour depth for Q100 flood, and apply a geotechnical factor of safety 2 to 3. check with Q500 (Q100 * 1.7)
8	Temporary-Runaround structure	Road Serviceability	Q25/ Q10/ Q2
		Allowable Velocity	Q10/Q10/Q2
9	Channel Clearing		

Note 1: The traveled way overtopping flood level identifies the limit of serviceability

Note 2: Q100 is for: Freeway, Multilane Non-Freeway, Two Lane facility with AADT ≥ 3000 and ramp, Q25 is for: Two lane facility with 1000 < AADT < 3000, and Q10 is for: Two lane facility with AADT < 1000, and Q10 is for: Two lane facility with AADT < 1000

Note 3: Hydraulic engineer approval is required to exceed the limit of 1.5"

Note 4: FHWA does not require economic justification for a bridge that causes less than 12" of backwater Therefore, a formal risk assessment will not be required

(1) INDOT's culvert design discharge magnitude (Q_{100}) is conservative in comparison to other states' culvert design discharge magnitudes. For example, Illinois uses Q_{50} as design discharge compared to Q_{100} by Indiana.
(2) INDOT's maximum back water limit criterion (1.5") for new alignment culverts is not found in neighboring states' design manual (Table 1.3). The maximum back water limit criterion becomes limit criterion for culvert design (culvert size) in many cases.

1.3 Bridge Design Policy Comparison

The main features of INDOT design policy are listed in Table 1.4. Comparison of INDOT's bridge design policy with policies from other states is not conducted because the SAC agreed to restrict the comparison for culverts only.

TASK 2: COST BENEFIT ANALYSIS

The cost benefit analysis is performed in the light of suggested revision in culvert hydraulics policy (Box 1). INDOT provided a total of sixteen culvert design examples including both new-alignment and replacement structures. These culvert designs are reviewed, and structures are redesigned (if needed) to have a maximum back water of 1' as suggested in the revised INDOT policy. A comparison of old design with new design is made to quantify the changes in culvert size and outlet velocity.

To convert culvert size reduction into actual dollar amount, a regression model (Section 2.3) is developed based on bid prices of more than 500 culverts. The bid price data for this analysis is provided by INDOT. Bid prices used in this analysis represent "fully loaded" prices of per unit length of finished work including all materials, time, and labor. Because of the competition, bid prices may be influenced by other factors that go beyond the cost of actual labor and materials alone.

2.1 Culvert Re-designing

Out of sixteen culvert designs reviewed, seven designs (referred as Group 1) used 0.14' maximum backwater, but can have up to 1' maximum backwater as per the suggested revision (see 'Culv7-NewAlg' sheet in Culvert_Ana_Rev2.xlx). The remaining nine culvert designs (referred as Group 2) either used 1' maximum backwater mostly because they were replacement structures, or 1' backwater was implemented with special permission from INDOT (see 'Culv9-Replace' sheet in Culvert_Ana_Rev2.xlx). Group 1 culverts were redesigned using HY-8 for maximum 1' backwater limit. There were twelve culvert designs (sample size) in Group 1, because in most cases each culvert site has two (alternative) proposed structures. Several (range: 3–7) alternative structures were tried until backwater reached the maximum limit of 1.0' ('Culv7-NewAlg' sheet in Culvert_Ana_Rev2.xlx).

Box 1: JTRP's suggestions for revision in culvert hydraulics policy.

JTRP CULVERT HYDRAULICS POLICY

June 1, 2010

EXISTING CULVERTS — Replace in Kind if:

- No Scour at the Outlet (*Velocity Upper Limit?)*
- No Upstream Structures Below Q100 Backwater Elevation
- No Complaints on File
- Model and Maintenance Show No Record of Road Overflow at Required Serviceability
- *Existing Culvert Size Meets or Exceeds Minimum Pipe Size*
- **Match or Decrease Existing Backwater (will require smooth and corrugated option)**
- **No Known Debris Problems**

NEW ALIGNMENT CULVERTS — Allow Higher Backwater than 0.14' if:

- DNR Permit Not Required (Drainage Area Less than One Square Mile)
- No Upstream Structures Below Q100 Headwater Elevation
- One Foot Maximum Backwater
- Culvert Size Meets or Exceeds Minimum Pipe Size
- Outlet Velocity Upper Limit? **Allow Up to a Maximum Velocity then Apply a Multiplier of the Tailwater Velocity if it is High.**

2.2 Specific Example of New Alignment Structures

Five structures in Group 1 are 4-sided concrete box culverts. Bid prices corresponding to the same culvert size (in terms of area) are compared for the original proposed structure and the reduced structure size after implementing the 1' backwater limit. There is a wide range of bid prices corresponding to same structure size (Fig.2.1 a – d). Factors affecting unit bid price include total length of finished work, competition among bidders, and site accessibility. Average saving as a result of reduction in structure size is presented in Table 2.2. One to one match (corresponding to same contact number) is not found in the provided data, and thus only general results are presented.

2.3 Specific example of replacement/special permission structures

There are nine structures where 1' backwater was used either because they were replacement structures or new structure with special permission of 1' backwater. In some cases, existing backwater was excessively high. These structures include CN-51750-US50 Seg. 7 struc-

TABLE 2.1
Reduction in culvert structure size due to increase in backwater limit to 1'

	Final Backwater (feet)	Decrease in culvert area (%)	Increase in outlet velocity %
Average	**0.79**	**−44**	**72**
Minimum	0.62	−21	2
Maximum	0.98	−62	326
Standard Deviation	0.11	12	93
Sample Size	12		

ture (3' diameter corrugated steel pipe) with a backwater of 9.5', SR66 Spencer County Dest#0800794 (10' diameter structural steel pipe) with a backwater of 4.4', and US 24 Newton County, Des. # 0200068 (4' × 3' concrete box) with a backwater of 3.5'. In eight out of nine proposed structures, 1' maximum backwater limit was implemented. In one structure special permission was provided for 3.02' backwater (US421 Carol County, Des. #0201034).

One particular revision suggested for existing culverts: *'Match or decrease existing backwater (will require smooth and corrugated option)'* may have detrimental effects on the proposed structures. As shown earlier, some existing structures may have excessive backwater due to either under design of the existing structure, or change in the land cover condition (e.g. increased urbanization) in the catchment area. Hence an upper limit (e.g., 1' backwater) should also be included as a part of existing culverts.

Bid price comparison of the exiting and replacement structures is presented in Table 2.3. For two replacement structures, existing structure and replacement structures are of 4-sided concrete box, hence comparison using both bid data and the regression model (Section 2.3) is performed (Fig. 2.2 and Table 1.3). For three structures, existing structures are of pipe type, and replacement structures are of 4-sided concrete box. For these three structures bid price for existing structure is calculated for equivalent size 4-sided concrete box structure (pipe size data is not available yet) using the 4-sided general regression model (Section 2.3). Five replacement structures presented in Table 2.3 has resulted in average 40% increase (range 29.5% to 53%) in culvert bid price. Remaining three structures are new alignment structure, and special permission was given for 1' backwater. Hence, no bid price comparison is made with for these three structures (see Culv9-Replace sheet in Culvert_Analysis_Rev2.xlsx).

2.4 General Linear Regression Model for cost-benefit analysis

INDOT provided the data for bid prices of culvert structures (3-sided and 4-sided structures) between year 2005 and 2010. Based on these data, a general linear regression model is developed for 3-sided and 4-sided structures, separately. Major steps involved in model development are briefly described below.

Step1: The data is cleaned up to have only 3-sided and 4-sided culvert structures. Accessories structures such as wing wall, head wall, retaining walls, tie-back wall, etc. were removed from the original data because these items were quoted separately from the culvert structures.

Step2: Necessary unit conversion is implemented to bring all data in a single unit format i.e. culvert structure in ft × ft, and bid price in $$ per unit length (foot) of the culvert structure.

Step3: Culvert sizes are represented in terms of their area, e.g. 6 ft × 4 ft culverts is represented by 24 ft^2 culvert area. No distinction is made when two structure sizes resulted in the same area e.g. 6ft × 4 ft and 8ft × 3 ft.

Step4: Three-sided and 4-sided structures are analyzed separately. Three-sided structures are in general higher sizes (average: 196 ft^2, range: 43 to 588 ft^2), compared to 4-sided structures (average: 42ft^2, range: 6 to 128 ft^2).

Step5: Logarithmic transformation ($\log_{10}$) is implemented in per unit bid price to stabilize the variance in the data.

Step6: Given bid prices are for year 2005 to 2010. For four sided structures, separating the data set into different years (to account for inflation) were tried, but final results are presented by combining all the data sets to cover wide range of structure sizes and large number of sample sizes. In the case of 4 sided structures final sample size (after removing outliers) is 433 and for 3-sided structures sample size is 137.

Step7: Linear regression model is implemented in SAS, and outliers are removed based on *cookd* values. Ten outlier observations (*cookd* > 0.02) were removed

TABLE 2.2
Average saving in bid price due to increase in back water limit to 1'. Note: Model is described in Section 2.3

Sl. No	Crossing Name	minimum structure Size for 0.14' back water	minimum structure size for 1.0' back water	average saving in the bid price per unit length (feet) of structure from data	% average saving from data	% saving from model
1	SR-58W					
2	CN-224400, Seg-11	7' × 3' CB	4' × 3' CB	$80	18%	12%
5	CN-222800, Seg-11	9' × 5' CB	5' × 4' CB	$392	58%	31%
6	LSR 11, Seg - 4	18' × 8' CB	12' × 6' CB	$682	44%	65%
7	RAMP2-US50, Seg-7	9' × 4' CB	6' × 4' CB	$181	31%	16%

Fig. 1 (d)

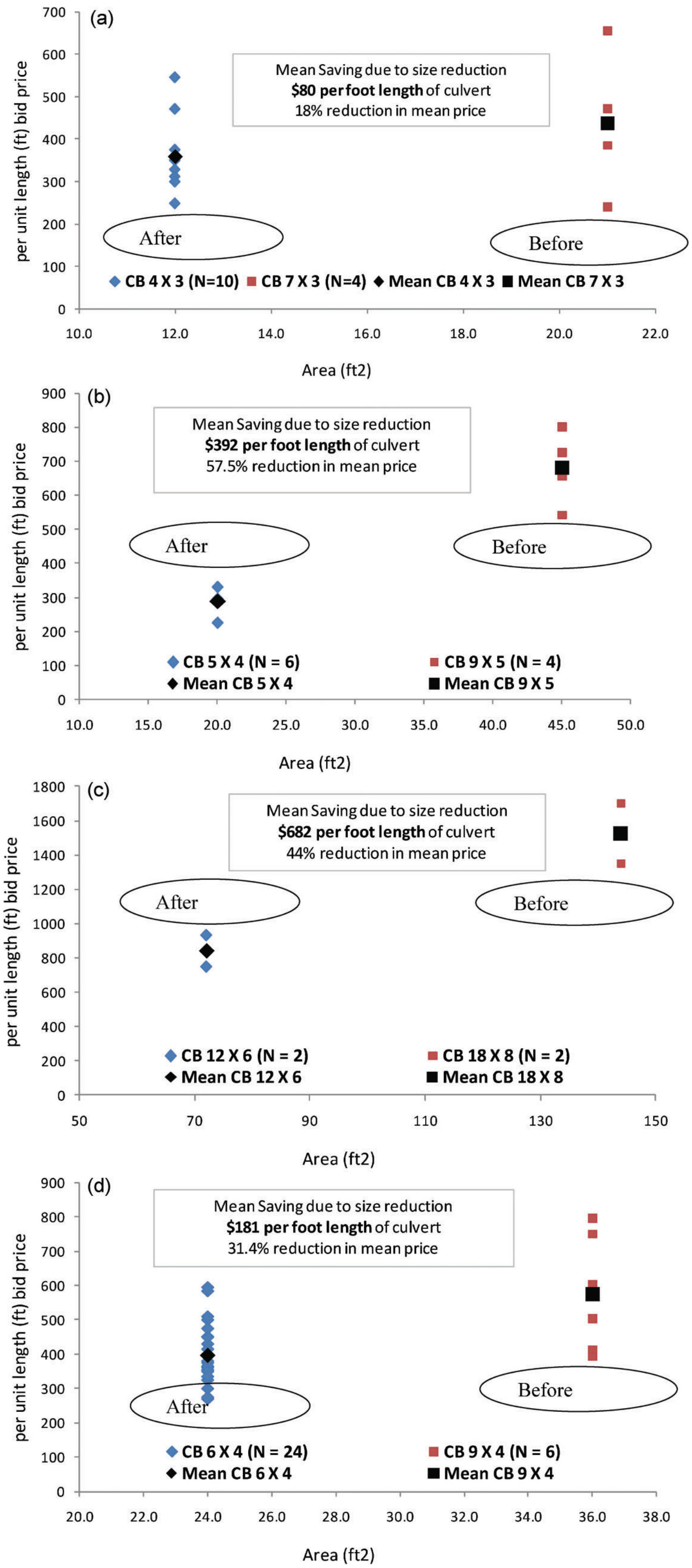

Fig. 2.1 Saving in culvert bid price due to increased in backwater limit to 1'

TABLE 2.3
Average increase in cost in replacement of existing structures

Sl. No	Crossing Name	Existing Structure	Existing backwater	Proposed Replacement Structure size	proposed backwater	average increase in the bid price per unit length (feet) of structure from data	% increase from data	increase in the bid price per unit length (feet) of structure from model	% increase from model	Remarks
1	US 24 Newton County, Des. # 0200068	4' × 3' conc. Box	3.1'	9' × 4' CB	0.79'	$218	61%	$151	42.50%	
2	CN-49600-US50, Seg-7	18' × 3' conc. Box	0.71	19' × 4' CB	0.68'	$136	19%	$252	38.30%	Note 1
3	CR1200N	1.25' CMP	1.06' (Note 3)	6' × 4' CB	1.01'			$121	40%	Note 2
4	SR66 Spencer County Des# 0800794	10' dia structural steel plate pipe	4.38'	12' × 8' CB	1.0'			$278	29.50%	
5	CN-51750-US50, Seg-7	3' dia corrugated steel pipe	9.5'	9' × 4' CB	0.87'			$176	53%	

Note 1: increase from data is calculated from 10*8 size structure because no 19*4 structure was available in the data
Note 2: no data correspond g to pipe structure is available. Hence for existing structure bid price is calculated from corresponding area 4 sided structures using the model
Note 3: In the case of existing structure (1.25 CMP) 95% of design discharge (116 cfs) was flowing as roadway discharge.

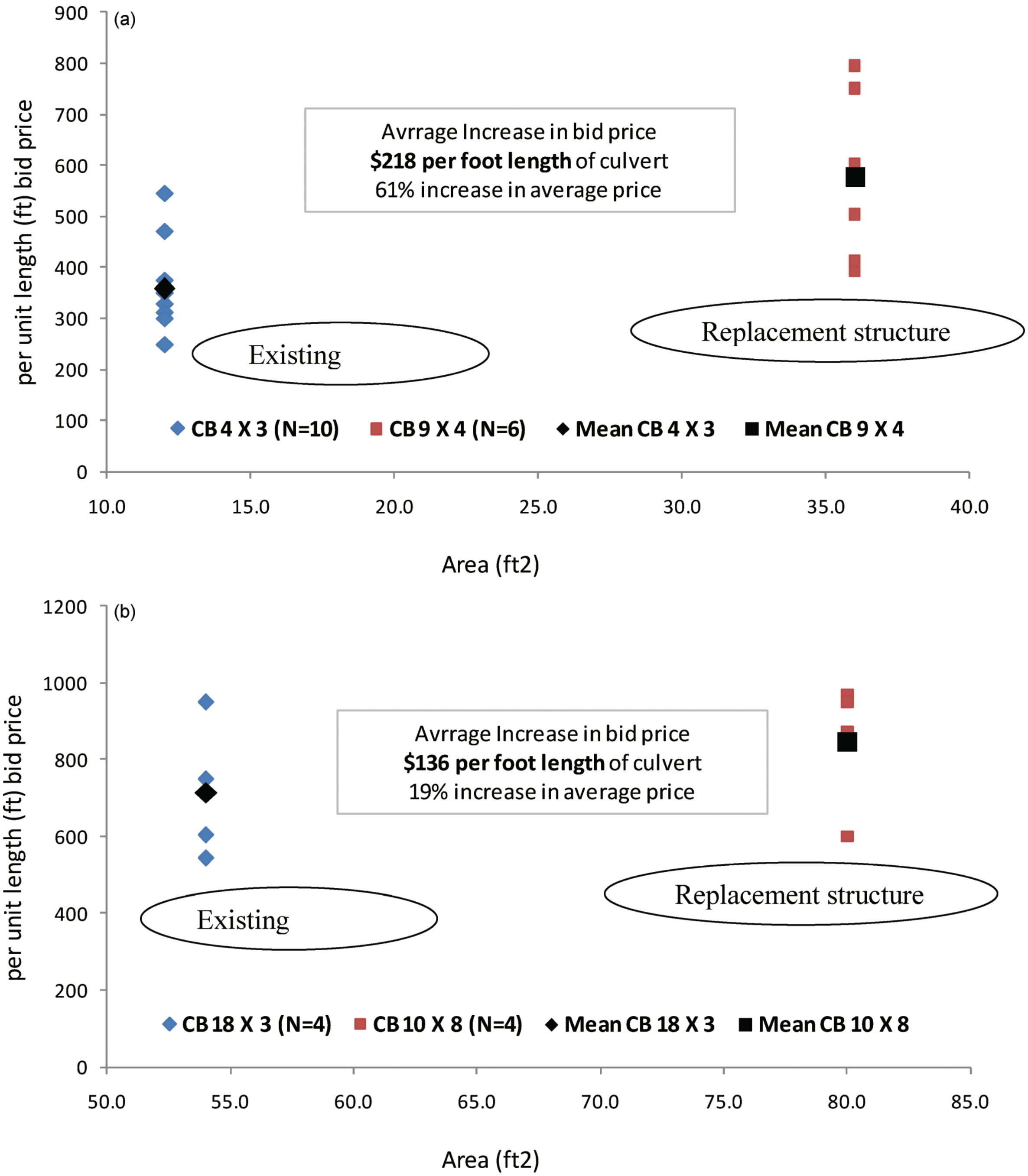

Fig. 2.2 Increase in culvert bid price due to replacement structure

TABLE 2.4
Parameter estimates of general linear regression model of four sided structures

Variable	Label	DF	**Parameter estimate**	Standard error	t Value	Pr > |t|
Intercept	Intercept	1	**2.4732**	0.01161	213.03	<.0001
slope	slope	1	**0.0064**	0.00022	29.03	<.0001

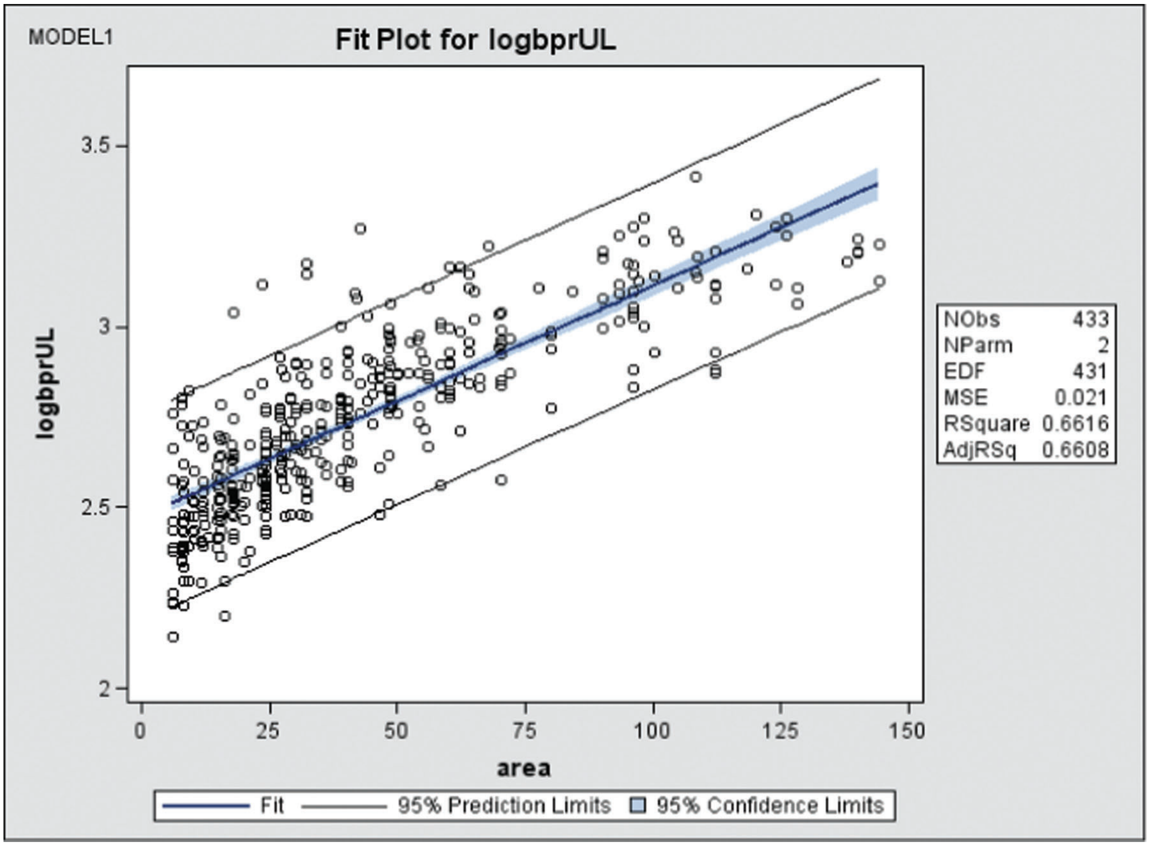

Fig. 2.3 General linear regression model for 4-sided structures.

from 4-sided structures and five outlier observations (cookd > 0.04) were removed from 3-sided structures.

2.3.1 Results: General Linear Regression Model for 4-sided structures

$$log_{10}(bdprUL) = m * (area) + c$$

Where *bdprUL* is the bid price per unit length ($$/ft), *m* is slope, c is intercept, and *area* in ft^2. Parameter estimates and statistical significance are given in Table 2.4. RSqaure of model fit is: 0.66 (Fig. 2.3). Diagnostics of linear model is shown in Fig. 2.4.

2.3.2 Results: General Linear Regression Model for 3-sided structures

$$\log_{10}(bdprUL) = m * (area) + c$$

Where *bdprUL* is the bid price per unit length ($$/ft), *m* is slope, c is intercept, and *area* in ft^2. Parameter estimates and statistical significance are given in Table 2.5. RSqaure of model fit is: 0.40 (Fig. 2.5). Diagnostics of linear model is shown in Fig. 2.6.

2.3.3 Discussion

Parameter estimates are found statistically significant for both 4-sided and 3-sided structures. Better model fit (RSqaure = 0.66) is found in 4-sided structures compared to 3-sided structures (RSqaure = 0.40). Four sided structure model provided conservative estimate of saving in 3 out of 4 structures shown in Table 2.2. Further investigation is needed to account for yearly inflation rate, and total length of culvert in the bid price model.

TABLE 2.5
Parameter estimates of general linear regression model of three sided structures

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	3.02623	0.02776	109.03	<.0001
slope	slope	1	0.00124	0.00013	9.54	<.0001

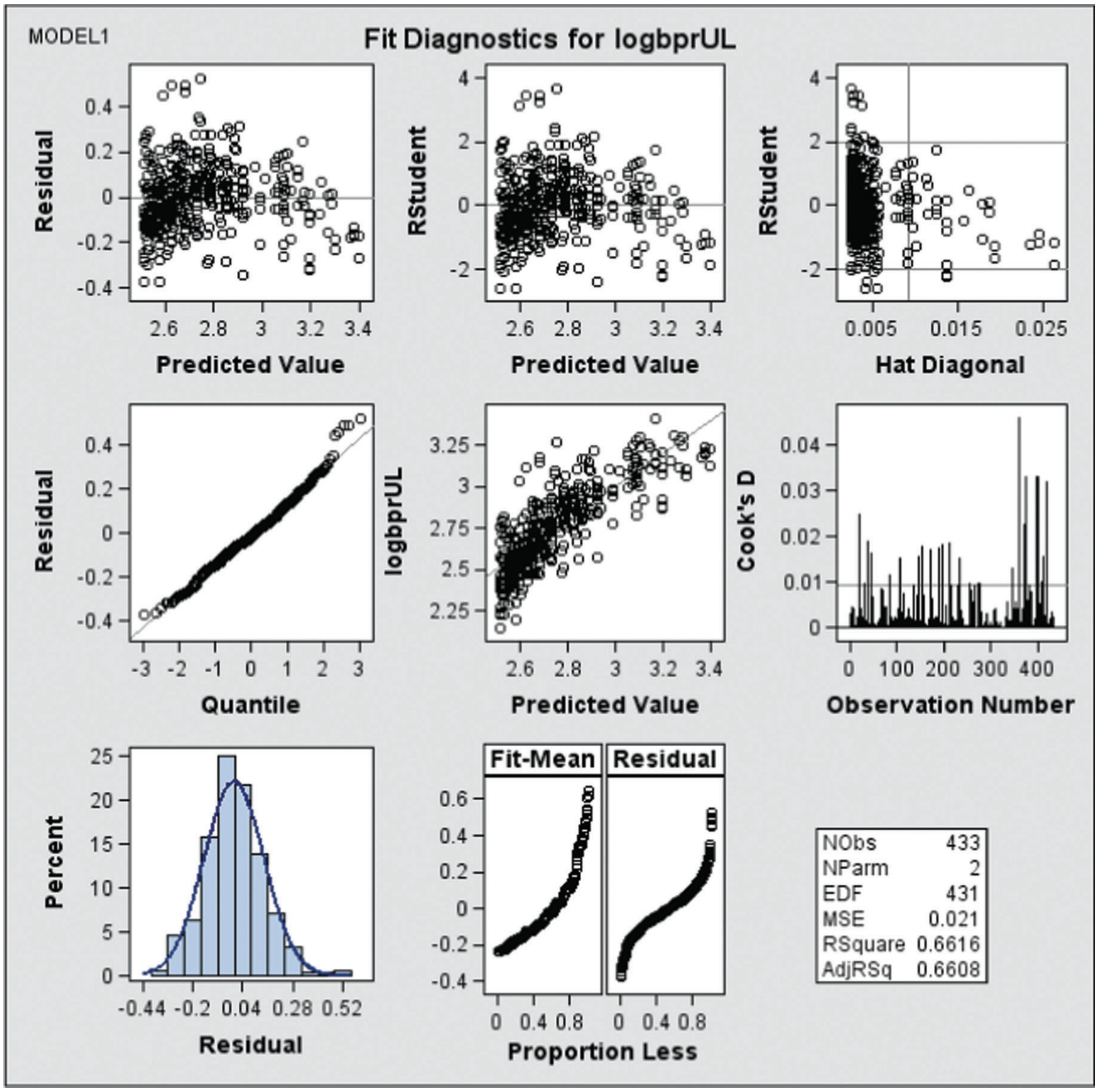

Fig. 2.4 Model diagnostics for 4-sided structures.

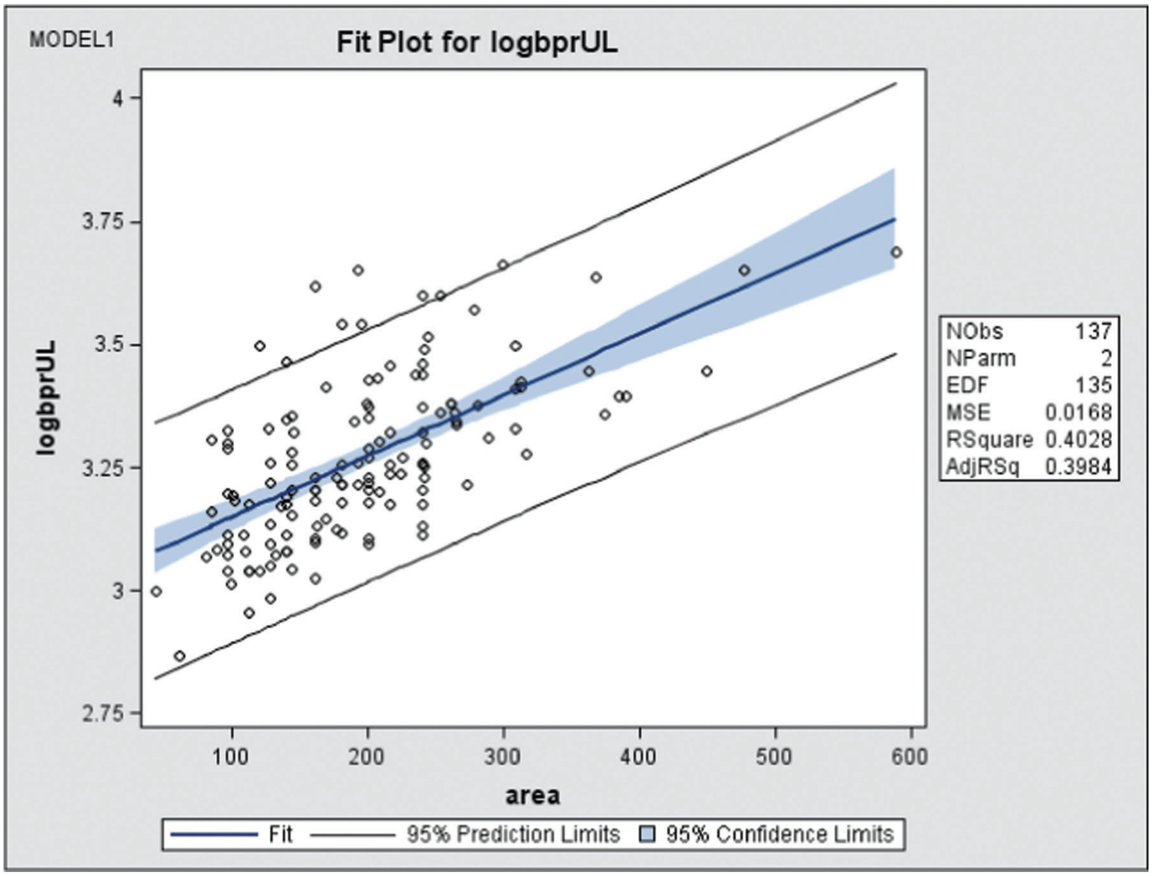

Fig. 2.5 General linear regression model for 3-sided structures.

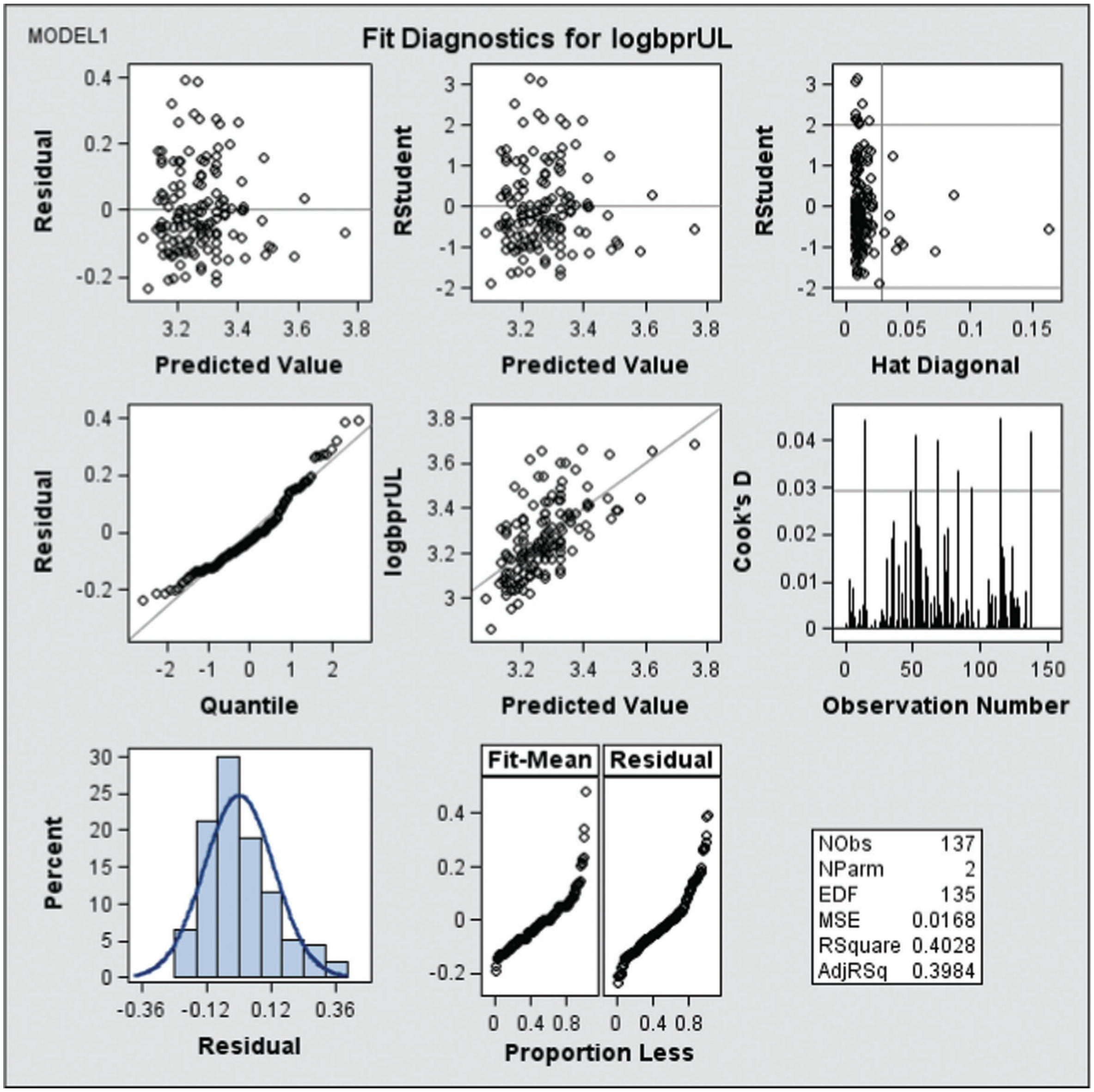

Fig. 2.6 Model diagnostics of 3 sided structures.

TASK 3: INVESTIGATE WAYS TO IMPROVE HYDRAULIC DESIGN

Investigation is carried out to determine sources of uncertainty on design flow calculations. Here uncertainty analysis for a specific example of culvert design is presented.

Culvert design for crossing CR 1200 N located in Section 34, Township 5 North, Range 6 West, Bogard Township in Epsom Quadrangle, Daviess County, Indiana, is reviewed for uncertainty estimate in the design calculations.

Proposed structure is a small culvert, hence preferred method of Q_{100} calculation is: (1) T20, and (2) Rational Method. (Fig. 29-6A, INDOT design manual)

Note 1: Design Q_{100} in the given report (provided by INDOT) was based on Rational Method. Differences in the rational method design estimate in the report (116.86 cfs) and the value presented here (138.3 cfs) can be due to differences in precipitation frequency estimates. Precipitation frequency estimate is based on 38.82970 latitude, and -87.03722 longitudes.

Note 2: TR20 calculation is based on composite CN = 76.5 (Hydrologic Soil Group: B; 93% Row Crop), and Huff distribution of design rainfall (Indianapolis area) for 1 hour storm.

Major Findings are:

1. Highest uncertainty (~ 2 fold increase in design discharge) comes from change in AMC from II to III.
2. HY-8 design performed in the study show that the proposed structures (6' × 4' Precast Concrete Box, and 9' × 4.71' Open Bottom Corrugated Metal Arch) fail to meet the design requirement of 1' maximum backwater for discharge higher than 116.86 cfs. For example, for

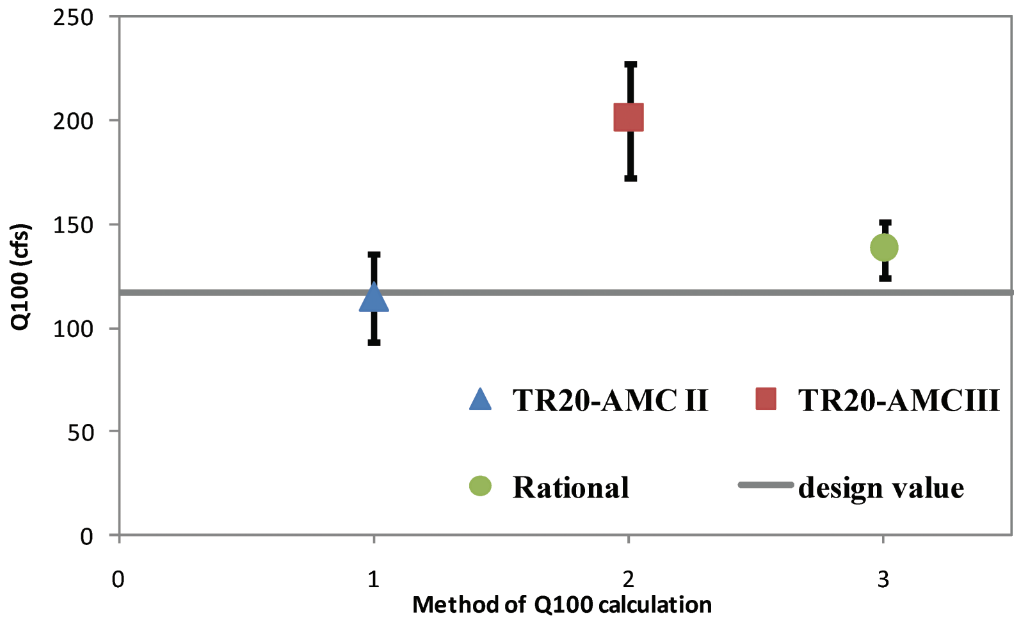

Fig. 2.7 Uncertainty in Q100 calculation (Error bar represent upper and lower bound of Q100 based on 90% confidence interval precipitation frequency estimate; AMC- Antecedent Moisture Conditions).

158.83cfs peak flow, backwater is 1.92' in 6' × 4' Precast Concrete Box.

Based on this analysis following recommendations are made to improve design discharge calculation:

1. Please mention latitude and longitude of the site location.
2. Design discharge calculation based on at least two methods of calculation (Preference 1 and 2, as given in Fig. 29-6A, INDOT design manual) should be presented in the report. In the case of small culverts, two preferred methods are T20 and Rational method.
3. Known sources of uncertainty (e.g. change in AMC, CN, precipitation frequency estimate) should be incorporated in Q_{100} calculation.
4. Design based on AMC III may be considered because high floods are more likely to occur in wet years compared to dry years. However, this issue should be discussed and decided by the SAC committee.
5. Guidelines should be made to incorporate Q_{100} uncertainty estimate in the culvert design (e.g. relaxation in 1' maximum backwater limit if AMCIII design discharge is used)
6. Please provide shape file (GIS data) for the delineated watershed for the culvert. It will be helpful in extracting the available digital data (e.g. soil hydrologic group, land cover, CN) for the study area. StreamStat can be used to delineate the watershed.

REFERENCES

Illinois (2011). Bureau of Local Roads and Streets, Manual, http://www.dot.il.gov/blr/manuals/blrmanual.html, (last accessed: 19 September 2011)

Indiana (2011). Indiana Design Manual, http://www.in.gov/dot/div/contracts/standards/dm-Archived/10English/index.html, (last accessed: 19 September 2011)

Kentucky (2011). Drainage Guidance Design Manual, http://transportation.ky.gov/Highway-Design/Pages/Drainage.aspx, (last accessed: 19 September 2011)

Michigan (2011). Drainage Manual, http://www.michigan.gov/stormwatermgt/0,1607,7-205--93193--,00.html, (last accessed: 19 September 2011)

Ohio (2011). Location and Design Manual, http://www.dot.state.oh.us/Divisions/Engineering/Hydraulic/LandD/Pages/LDManual,Volume2.aspx, (last accessed: 19 September 2011)