STORMWATER CATCHPITS CAPACITY IN NEW ZEALAND – BETWEEN THEORY AND PRACTICE

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ABSTRACT

New Zealand Territorial Authorities (TA's) infrastructure design standards adopt different designs for catchpit inlets, all based on the same well known flow concept of kerb back entry (kerb opening), channel grates or a combination of both.

During road design, catchpit inlets are modelled, designed, and located to allow all road runoff to be diverted to the stormwater network system. Most designs are based on a theoretical prediction of the specific catchpit capacity, if available, or conservative practice values stated in the standards. In the theoretical calculation of catchpit inlet capacities, designers have to assume values of a number of important input parameters, hence, the consistency of the results are often variable. A number of capacity calculations of various catchpit inlet types, using the HEC 22 method with variable input values, are presented in this paper. This highlights that designers may end up with a wide range of "suspect" capacity values if well defined inlet component design parameters and TA specific design limitations are not available.

In construction, many channel slopes and catchpit openings are not built to the standard design. Calculations of "as built" capacities using the HEC 22 method compared to "as designed" capacities, indicate that changes to original design features have a significant effect on the capacity of the catchpit inlet and hence may result in unpredicted overland runoff during a storm event.

A field survey of a number of poorly constructed catchpits in the Auckland area has lead to a better understanding of the reasons behind many construction problems.

Conclusions and recommendations from this work provide a good starting point for the industry to provide innovative solutions to the problems.

Keywords

Stormwater catchpit, road runoff, stormwater inlet design, road surface drainage

PRESENTER PROFILE

Husham holds B.Sc Civil Engineering and M.Sc Soil Mechanics and Foundation Engineering degrees from the University of Baghdad – Iraq. He is currently member of IPENZ, CPEng, and IntPE.

Since his graduation in 1972 Husham has had active roles as an engineer and senior engineer in design, construction, and quality management of large scale construction projects such as bridges, water treatment plants, industrial plants, and building complexes.

From 1983 to 1993 Husham held the position of Research Engineer in the Building Research Centre of his native country, Iraq, where he worked in the field of building materials and technologies. During that period he published 17 research papers in local and international journals and conferences and patented 3 new building material products.

Upon his arrival in New Zealand in 2002, Husham jointed a leading civil construction company as a Project Engineer, joining Humes in 2009 as a member of a newly established Technical Team. Since then he has been involved in various R & D project, technical management of product supply to major contracts, customer and sales training and technical support.

1 INTRODUCTION

Effective drainage of highways and urban road surfaces is essential for the maintenance of road service levels and the provision of traffic safety. Excessive water on the road can interrupt normal road users activities, cause unacceptable splash and spray hazards, limit visibility of drivers, reduce skid resistance, and reduce steering and braking control.

The proper design of road surface drainage requires the consideration of design storm water runoff, collection system capacity, and the allowable spread and depth of water on the pavement for various road locations and rainfall events.

Designers often spend a lot of time and effort to precisely calculate the stormwater runoff for various design rainfall events, however, the calculation of the collection inlet capacity and spacing is usually based on rational, highly conservative, values specified by various New Zealand TA’s.

New Zealand TA infrastructure standards cover more than 12 different collection system designs (Humes 2006a), all based on the simple concept of a grate or kerb opening, or a combination of both. However, both the product suppliers and the TA’s do not have an accurate and consistent methodology for the calculation of the capacity of these systems. Designers have to rely on the rational values of the standards, or work the capacity out from first principles. An exception is the collection system developed by Max Q Limited in Australia, where design curves based on actual testing are made available by the suppliers (Humes 2006b).

A design guide based on the first principle calculations of inlet capacity has been developed in New Zealand by The Ministry of Works and Development – Roading Directorate in November 1977 (G.J. Oakden 1977), which involves relatively simple design methods, charts, and examples. Alternatively the US Federal Highway Administration’s “Urban Drainage Design Manual”, HEC-22 (Federal Highway Administration 2001), design methods are practical tools to calculate the capacity of various collection systems. Commercial design softwares based on HEC-22 is also available worldwide.

New Zealand Engineers who wish to use first principle calculations in the design of road surface drainage, immediately face the fact that most New Zealand TA’s have no standard requirements that specify various input elements of the design. Furthermore, New Zealand commonly uses grates, which represent an important capacity element. These grates have different geometries compared to the HEC-22 rated grates meaning that inaccurate capacities may be arrived at irrespective of the accuracy of the calculation method (Captain, et al 2009).

Inaccurate construction practices represent another problem that design engineers may face, slopes and levels of all components play an important role in determining the actual capacity of the inlet, and hence construction should be precisely as per design to achieve the design capacity. Badly constructed inlets are also more prone to clogging, another area where expectations of the designers and asset owners can be compromised.

The aim of this paper is to show how various input factors affect the capacity of different types of catchpits, when HEC-22 first principle methods are used. A design spread sheet based on HEC-22 was developed, and various input data was used and graphically represented. The capacity of wrongly constructed examples was also calculated and compared to the capacity of same units constructed as per design.

Confusion regarding the terms used to define each component of the stormwater collection system is commonplace; sumps, cesspits, and catchpits are typical terminology used in this field. To avoid further confusion, the following terms proposed by MOWAD Design Guide (G.J. Oakden 1977) will be used:

“**An Inlet** is the structure which allows water to be removed from the surface, eg. a grate or kerb opening.

A catchpit is the space beneath an inlet, which traps debris and transfers water to underground pipe.

A sump is a catchpit either at the bottom of sag or where water is static above the inlet”

2 DESIGN FACTORS

2.1 INLET CAPACITY IN SUMP CONDITION

Kerb opening capacity is calculated using weir capacity formulas at low water level and orifice formulas for high water level over the opening. Figures 1 & 2 include HEC-22 Charts for weir condition with depressed and undepressed channel respectively, Figure 3 includes chart for orifice condition calculations.

2.2 INLET CAPACITY IN CATCHPIT CONDITION

The HEC-22 inlet capacity calculation method uses a number of calculations steps involving many rationally and mathematically developed equations and charts. For the purpose of developing this paper, a spread sheet has been developed to facilitate calculations and minimize the use of charts; Figure 4 includes a PDF copy of this spread sheet, and Figures 5 & 7 show the grate capacity factor charts that should be used in conjunction with this sheet.

Figure 1: Depressed Kerb Opening Inlet Capacity in Sump (US FHA 2001)

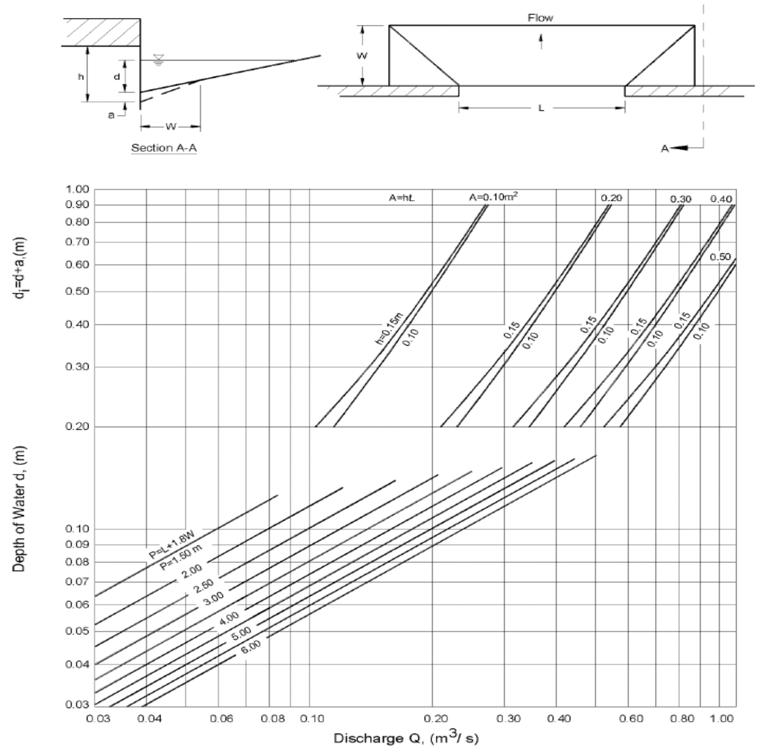


Figure 2: Undepressed Kerb Opening Inlet Capacity in Sump (US FHA 2001)

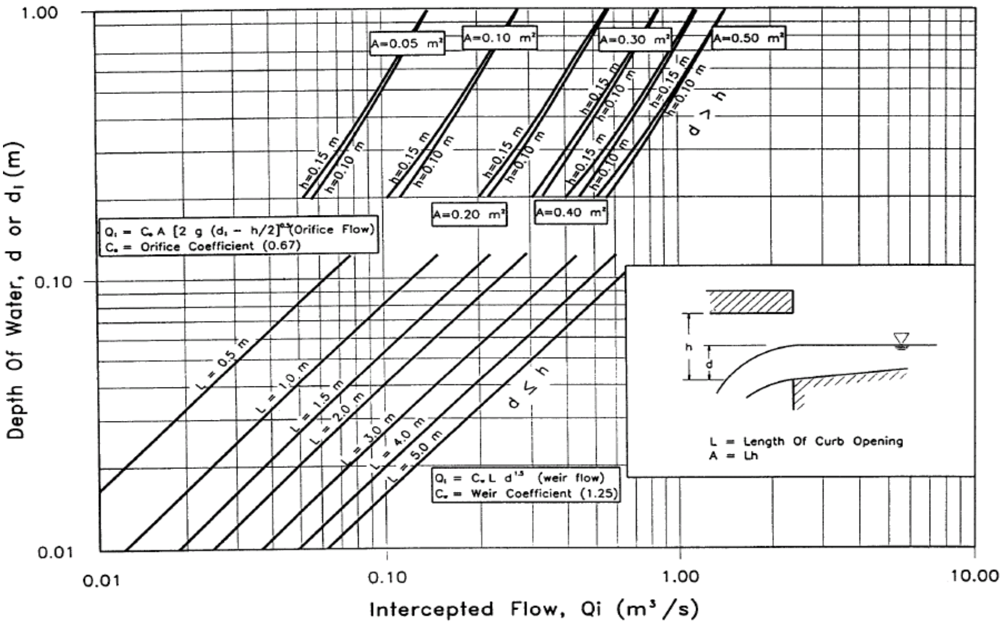


Figure 3: Grate Inlet in Sump (US FHA 2001)

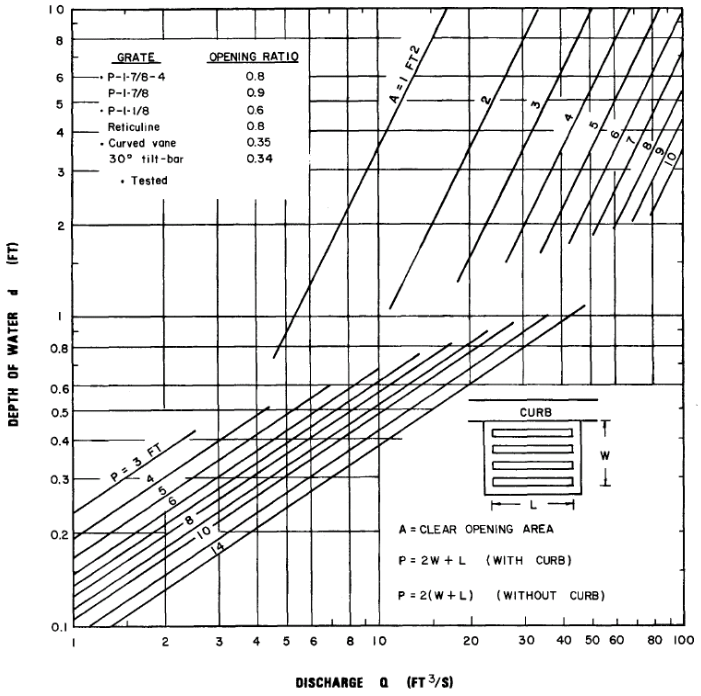
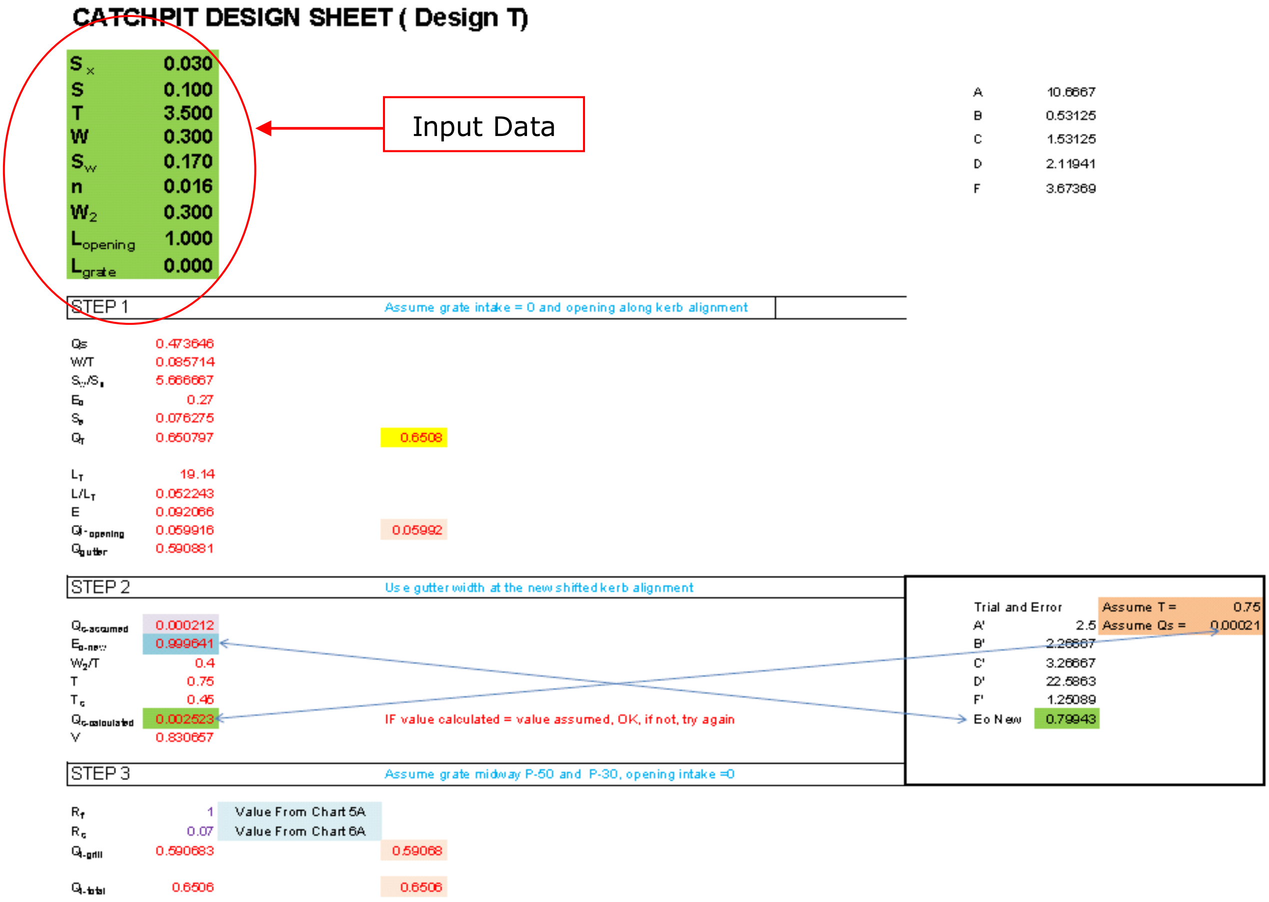


Figure 4: Inlets Capacity Spreadsheet in Catchpit Condition



CATCHPIT DESIGN SHEET (Design T)

S_x	0.030
S	0.100
T	3.500
W	0.300
S_w	0.170
n	0.016
W_2	0.300
$L_{opening}$	1.000
L_{grate}	0.000

Input Data

A	10.6667
B	0.53125
C	1.53125
D	2.11941
F	3.67369

STEP 1 Assume grate intake = 0 and opening along kerb alignment

Qs	0.473646	
W/T	0.085714	
S_w/S_x	5.666667	
E_o	0.27	
S_e	0.076275	
Q_T	0.650797	0.6508
L_T	19.14	
L/L_T	0.052243	
E	0.092066	
$Q_{i\text{-opening}}$	0.059916	0.05992
Q_{gutter}	0.590881	

STEP 2 Use gutter width at the new shifted kerb alignment

$Q_{c\text{-assumed}}$	0.000212	
$E_{o\text{-new}}$	0.999641	
W_2/T	0.4	
T	0.75	
T_s	0.45	
$Q_{c\text{-calculated}}$	0.002523	IF value calculated = value assumed, OK, if not, try again
V	0.830657	

Trial and Error		Assume T =	0.75
A'	2.5	Assume Qs =	0.00021
B'	2.26667		
C'	3.26667		
D'	22.5863		
F'	1.25089		
Eo New	0.79943		

STEP 3 Assume grate midway P-50 and P-30, opening intake =0

R_f	1	Value From Chart 5A	
R_s	0.07	Value From Chart 6A	
$Q_{i\text{-grill}}$	0.590683		0.59068
$Q_{i\text{-total}}$	0.6506		0.6506

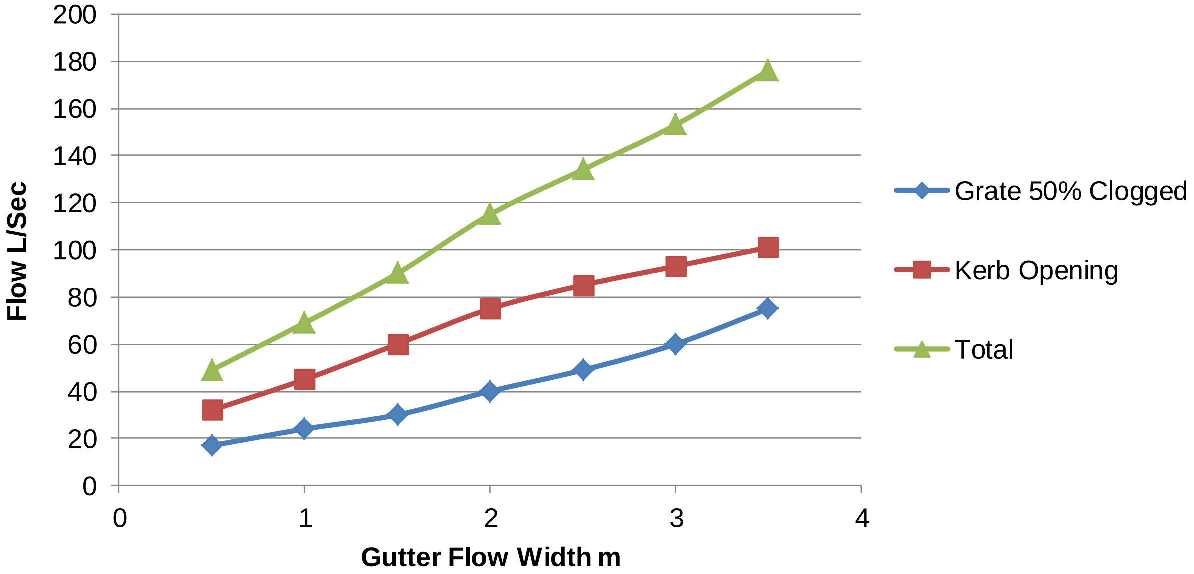
2.3 DESIGN PARAMETERS AND CAPACITY

2.3.1 GUTTER FLOW WIDTH (WIDTH OF SPREAD T)

When the geometry of the road is already known, the Engineer's first step in calculating the capacity of catchpit or sump inlet is to select the allowable width of spread on the road during the design storm. The width of spread governs the depth of water on sump inlets which is the basic input parameter in calculating the capacity as shown in Figures 1 to 3.

The allowable width of spread for various road widths and uses should be specified by the asset owners (TA's in New Zealand), and selected to achieve both safe access of vehicles, and convenience and safety of road users, during design storms.

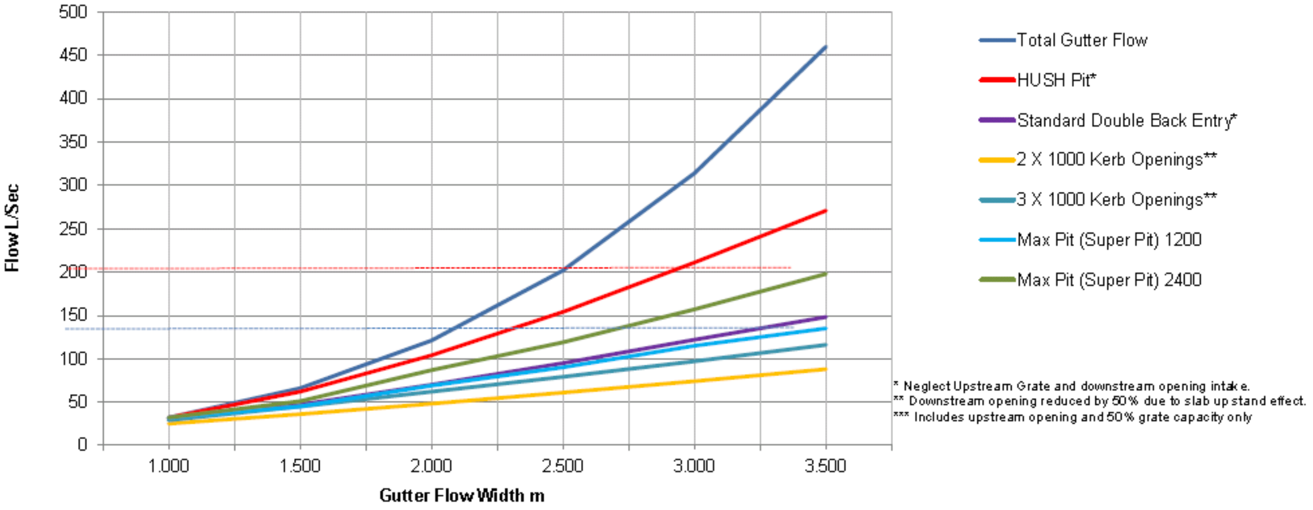
Figure 5 :Capacity of Standard Double Catchpit (Sump) - As Designed



The results of standard sump inlet calculations shown in Figure 5 indicate that substantial change in capacity may be expected with change of design width of spread. Where road condition allows, a 3.5m width of spread might be practical. At 3.5m only one lane out of two or more lanes will be covered and the height of water at the kerb will be less than the full kerb height. In such condition a design capacity of up to 100 L/Sec (neglect grate capacity) may be achievable. However, if the road is two way-one lane road, and the position of the sump is near a pedestrian crossing, or if there is any other factor that reduces the allowable spread to, say 0.5m, the design capacity should be not more than 30 L/Sec.

For the catchpit condition, inlet capacity calculations using the spread sheet in Figure 4 for a 5% grade road, indicate that when width of spread changes from 1.0m to 3.5m, total gutter flow increase from about 30 to more than 450 L/Sec. Intake capacity of all types of inlets also increases (mainly due to increase in water height), but this may not be adequate to reduce road water depths to safe levels.

Figure 6: Inlet Capacity of Common NZ Catchpit Types (S_L=5%)

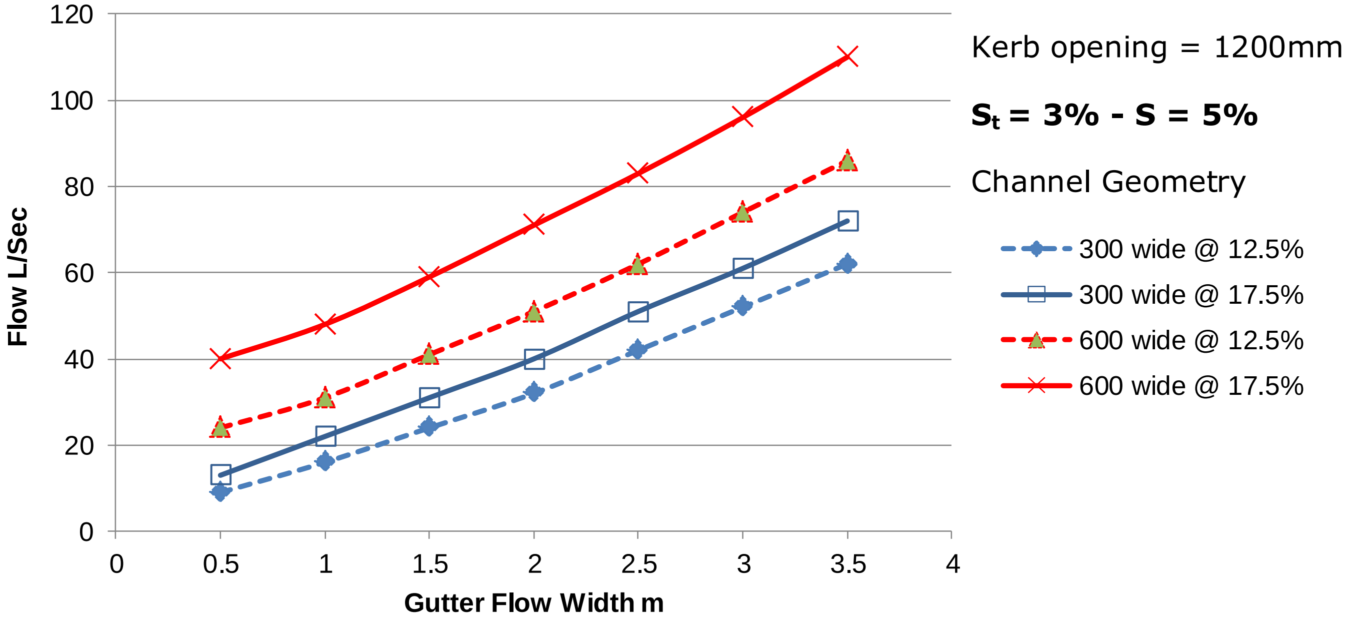


* Neglect Upstream Grate and downstream opening intake.
** Downstream opening reduced by 50% due to slab upstand effect.
*** Includes upstream opening and 50% grate capacity only

2.3.2 DEPRESSED CHANNEL GEOMETRY

The change of channel width and slope affects the capacity of catchpit inlets significantly. It is a good engineering practice to change the geometry of the channel to improve the capacity of inlets. However, most designers in New Zealand restrict themselves to the standard channel width of 300mm. The results in Figure 7 indicate that increasing the slope of the narrow 300mm channel alone will result in a limited increase in kerb opening inlet capacity, while increasing channel width to 600mm results in a two fold increase in capacity.

Figure 7: Capacity of 1200mm kerb opening in catchpit conditions



2.3.3 GRATE GEOMETRY

Grate design and geometry is one of the important factors that govern the capacity of both catchpit and sump inlets. HEC- 22 charts and formulas are based on 7 types of grates that were hydraulically tested by the Bureau of Reclamation for the highway administration (Federal Highway Administration 2001). Most HEC- 22 standard grates are substantially different in geometry from the grates commonly used in New Zealand, this make an accurate calculation of inlet capacity in New Zealand almost impossible. Unless a proper hydraulic evaluation of New Zealand grates is completed, the only solution available to the design engineer is to represent the characteristics of the selected grates as an estimate on the most appropriate HEC 22 charts (with HEC 22 grates).

For sump conditions, Figure 3 shows the input factors to calculate the capacity of any grate type. As the discharge calculations are based in this case on the simple hydraulic calculation of either weir or orifice capacity, it is possible to specify the type of grate used, calculate the geometrical parameters required in the above chart, and accurately find the capacity for various water depths.

Figure 8: Grate Inlet Frontal Flow Interception Efficiency (US FHA 2001)

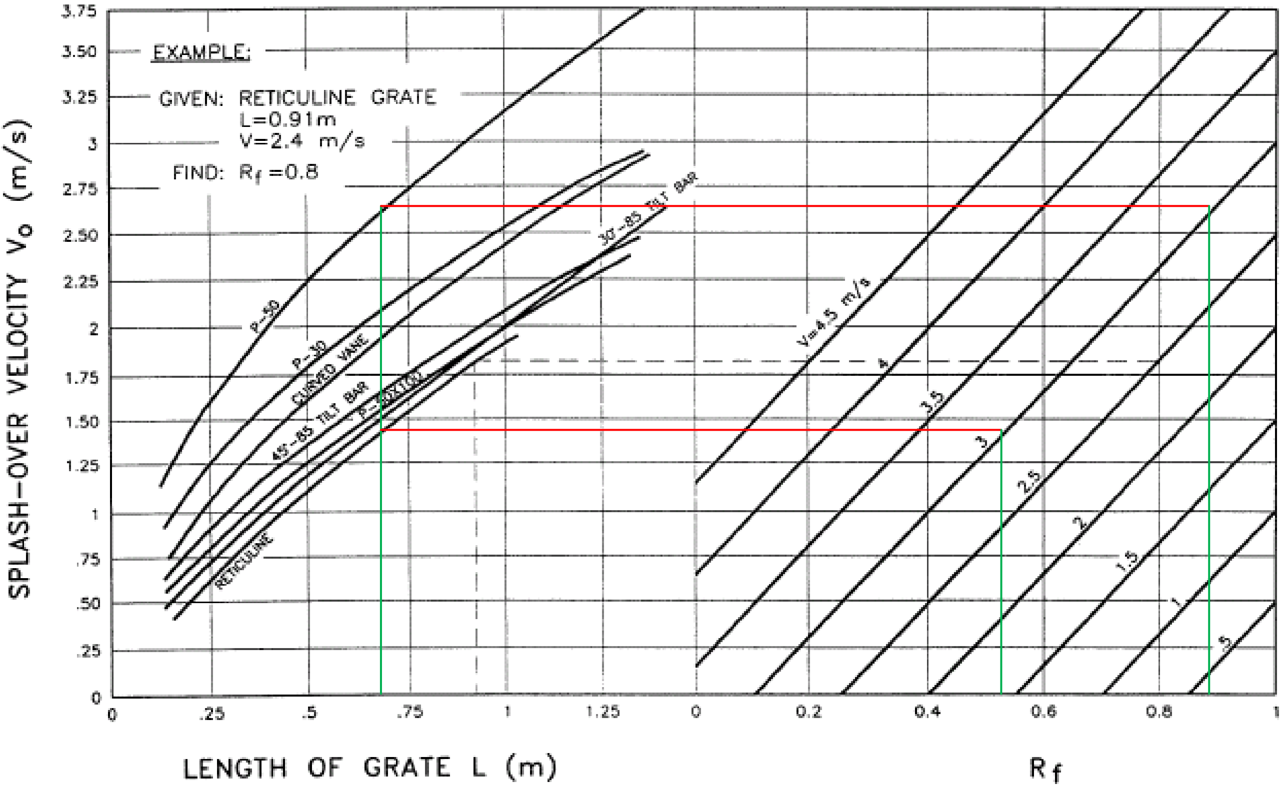
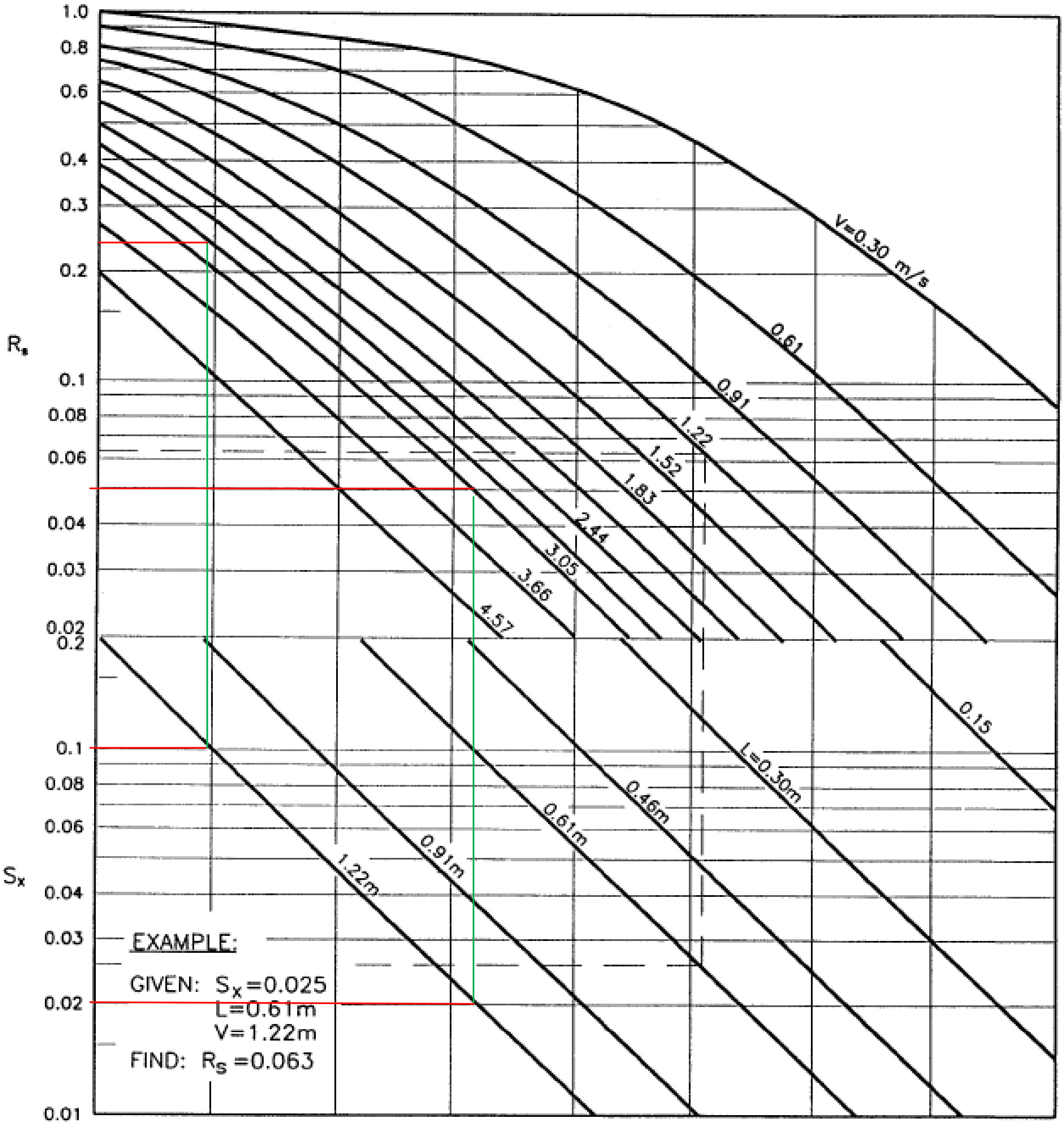


Figure 8 indicates how grate type affects the capacity of the catchpit inlet with grates of the same dimensions. The example on Figure 8 indicates that for a 650mm grate with gutter flow velocity of 3.0 m/Sec, type P-50 grate front will have 90% efficiency while a “rectangular type” grate of the same length will only have 53% efficiency. Figure 8 also indicates that the effect of grate type is much less significant when the velocity of flow is low; therefore, the grate geometry effect could be neglected in flat road and low runoff cases.

Figure 9: Grate Inlet Side Flow Interception Efficiency (US FHA 2001)



Unlike the front intercept grate efficiency, Figure 9 indicates that side flow intercept efficiency is not a function of the grate type, but of grate length, road geometry, and gutter flow velocity. The side flow component increases with increase of the grade of the rode, example on Figure 8 indicates that for a 1200 mm long grate and gutter flow velocity of 3.0 m/Sec, side intercept efficiency in 2% grade roads is 2% only, while that in 10% grade roads is about 24%.

Another important problem with commonly used New Zealand grates is that most are designed to capture dish channel flow rather than gutter flow. New Zealand cast iron grates are typically concave downward, causing the grate to be sloping about 5% in the wrong direction. This "negative" slope should be subtracted from channel slope when calculating the capacity of kerb inlets, particularly in the case of fully clogged gutters. Detailed discussion of this effect is included in the construction considerations section.

2.3.4 LOAD RATING AND SLAB SUPPORTS

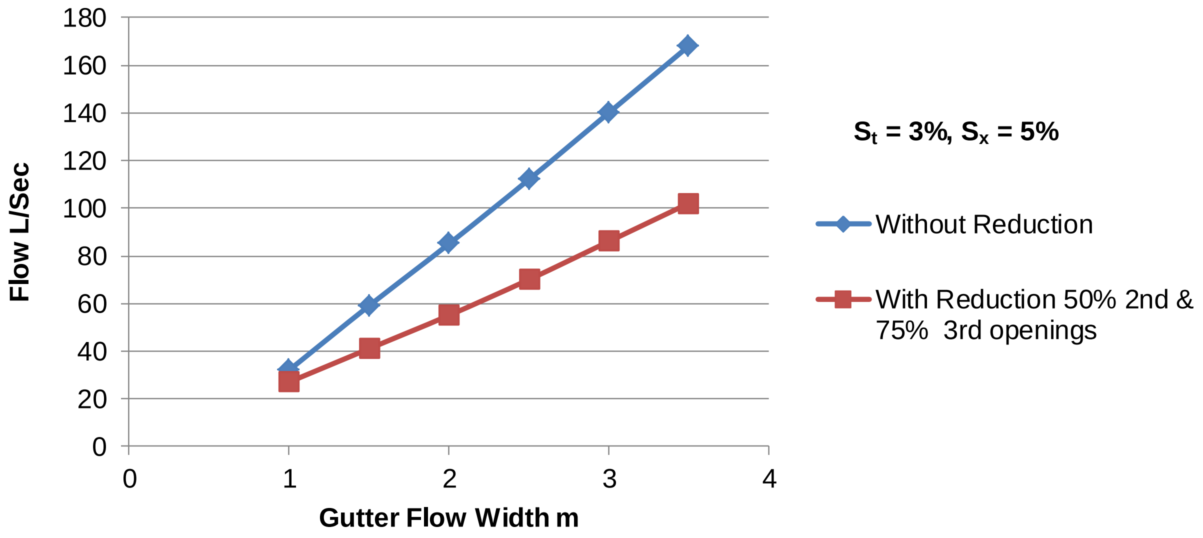
The NZTA Bridge Manual requires all roadway structures to be designed for a live load, HN-HO-72, as defined in that manual. The defined roadway is the area bounded by either the face of the kerb or the face of a guardrail or other barrier (NZTA 2001). This excludes the kerb from this design requirements, nevertheless, most structural designers prefer to design kerb opening slabs to carry this unrealistic load, which leads to problems that affect the hydraulic efficiency and hence the capacity of the openings as follows;

- High live load requires thick sections to carry load; therefore it is common to design kerb opening slabs with 100mm thickness. Considering the limited height of kerbs in New Zealand, 150mm or 125mm, a 150mm thick slab will leave very limited space to accommodate kerb openings with enough height to discharge reasonable quantities of water.

- To limit the slab thickness to 100mm, designers may propose reducing span by adding support at close intervals. HEC-22 indicates that slab support flush with the kerb line can substantially reduce the capacity of kerb openings. HEC-22 refers to tests on actual installations, and indicates that up to 50% of the capacity could be lost in the downstream openings.

  Applying the above concept on a 3.00m long kerb opening at one span, and 3 spans (effective length = 1.75m), Figure 10 below clearly shows the loss in capacity of the catchpit.

Figure 10: Effect of Multiple Slab Support on Kerb Opening Inlet Capacity



2.3.5 CAPACITY OF LEAD PIPES

It is common practice in New Zealand to specify a default lead pipe diameter for catchpits and sumps, usually without considering the actual maximum intake capacity. For high capacity units, mainly in sump conditions, the size of pipe might limit the discharge capacity of the system to that of the pipe rather than the capacity of the inlet. Designers need to calculate the maximum capacity of the structure during design storms, and select the diameter of the lead pipe to discharge this amount of water.

2.3.6 FUNCTION OF CATCHPITS AND SUMPS

Catchpits and sumps are built on roads to take out the stormwater runoff from the road to the under ground piping system. They should not be considered as stormwater treatment devices which require water to flow at slow rates for sediments to be captured. The required function is to remove water at the design rate, normally as quickly as possible. Some treatment inserts significantly reduce the capacity of the pits and affect their long term performance.

3 CONSTRUCTION FACTORS

3.1 CHANNEL AND KERB GEOMETRY

Field observations of many catchpit and sump inlets constructed in Auckland and other North Island Regions show a wide variety of construction problems, it is believed that most of the problems in achieving design geometry of the inlets are attributed to the following factors;

1. The standard width of channel in New Zealand is 300mm, while most of the grates used are 450mm or more in width.
2. The standard height of kerb is 150mm or, in some cases 125mm, while the design of kerb openings are based on kerb heights of 165mm or 200mm at the opening.
3. The responsibility for achieving design requirements at construction stages is divided between drainlayers, kerb layers, and road constructors.

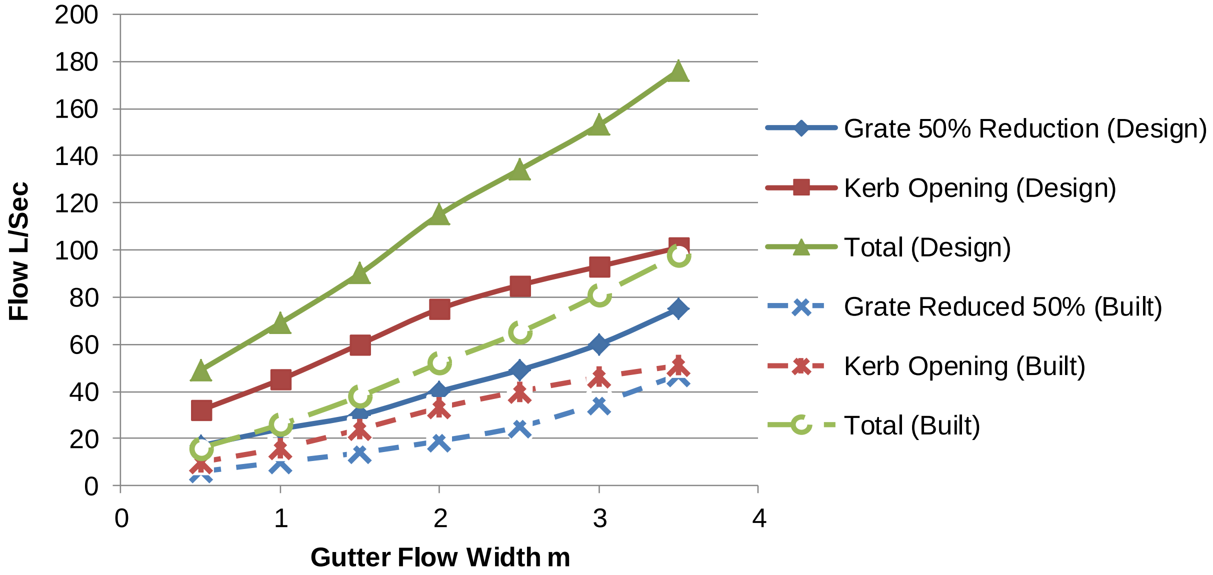
Both points 1 & 2 require highly skilled people to do the site work, preferably under supervision of foremen or engineers who clearly understand the effect of channel and kerb geometry on the hydraulic performance of the structure. Unfortunately a lack of clear responsibilities and supervision, often results in the design goals not being achieved.

Examples below outline wrongly constructed channel and kerb geometry, and the calculation using HEC-22 method to illustrate the effect:

1. Standard double catchpit was constructed in Papakura where the standard height of the kerb is 125mm. The standard kerb blocks used have a beam depth of 75mm on top of the opening. During construction, the channel has not been depressed but left at the same level as the standard channel. This construction has reduced the depth of water at the opening and on top of the grates by 40mm and left the inlet with 50mm opening height only.

   Capacity of both designed and as built options were calculated for sump condition and shown in Figure 11 below;

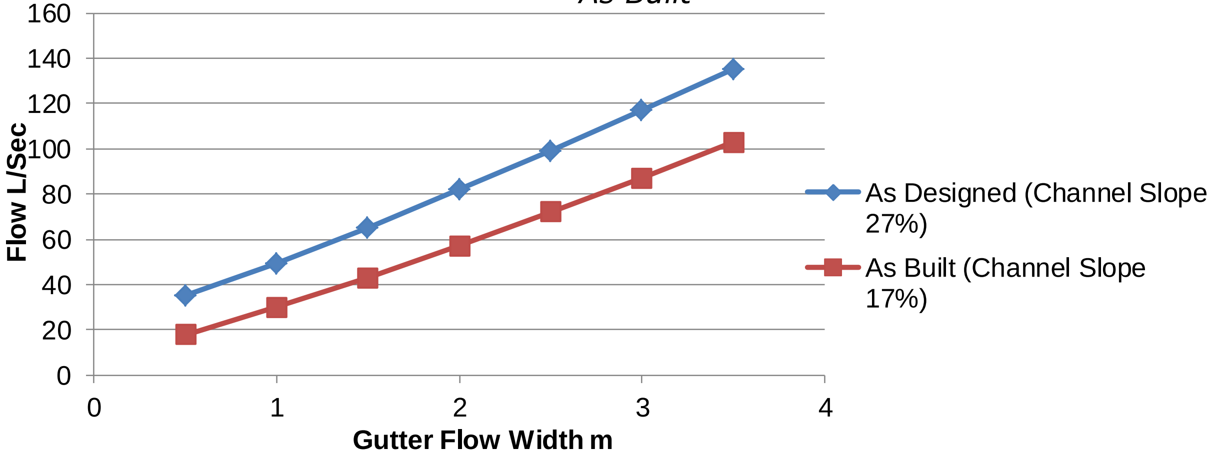
Figure 11 :Capacity of Standard Double Catchpit (Sump) - As Designed



The figure shows that more than 50% of the capacity of the inlet is potentially lost due to the wrong construction practice outlined in this example.

2. Auckland, North Shore's single and double splay pits are designed where the channel is further recessed when approaching the openings from the standard 17% to 27%; however, many pits are built without properly recessing the channel or without any recess at all. To calculate the effect of this wrong construction practice on the capacity of a double splay catchpit, Figure 12 shows the capacity as designed and as built of a double splay pit constructed on a steep road of 10% grade.

Figure 12 : Capacity of Double Splay Catchpits - As Designed and As Built



3.2 WATER FLOW PATH AND CLOGGING

Some of the commonly used catchpits in New Zealand, such as standard pits and splay pits, are designed with a rather complicated path for water to flow from the kerb opening to the catchpit of sumps. Such flow paths need careful and precise site installation and construction if a point of attraction for debris and sediment that clog the kerb opening at later stages, is to be avoided.

Figure 13: Standard Catchpit Detail (WCC 2003)

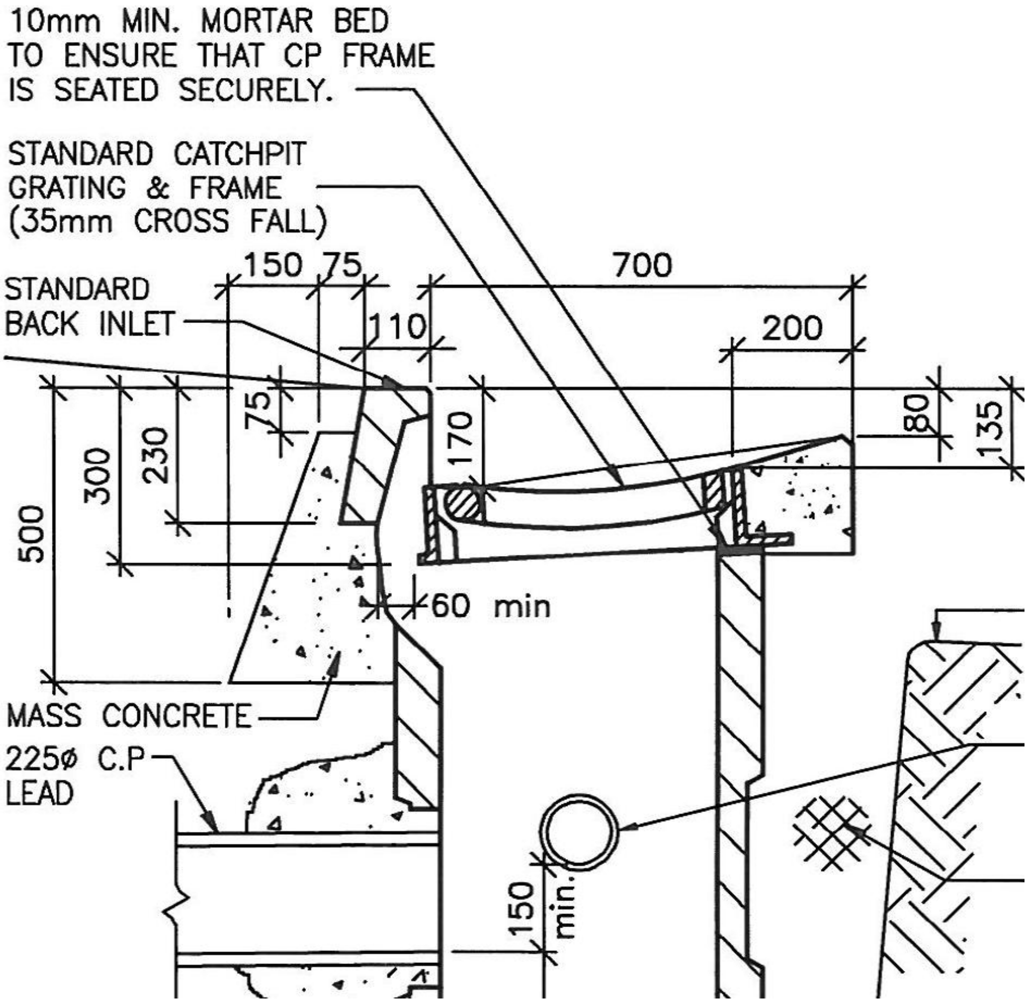
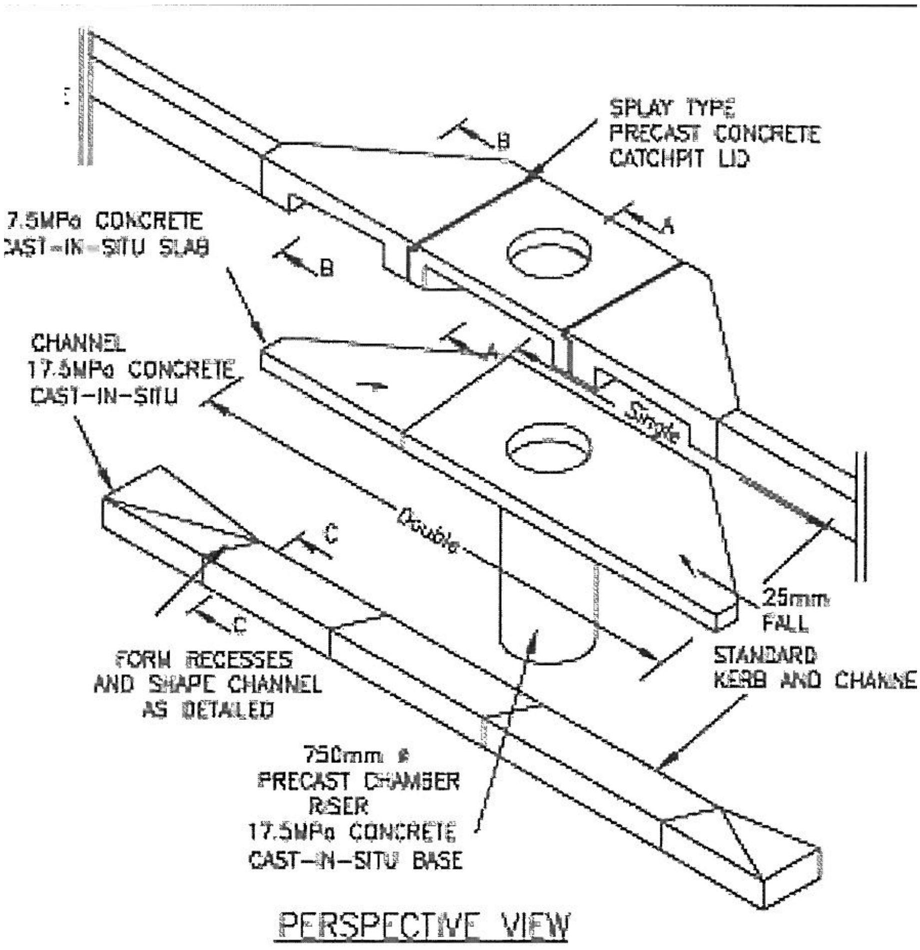


Figure 13 shows typical detail of New Zealand's most popular standard catchpit (WCC 2003). This detail clearly shows that achieving a water flow path from the kerb opening to the pit as per design, which allows free water flow at all times, without clogging with debris, requires the constructors to correctly achieve the following:

- Installation of the pit in the correct position with the top exactly 300mm below top of kerb level.
- Install the grate exactly in position and to the design slope, shifting the grate to kerb side will reduce the already small 60mm throat and increase clogging. Note that the grate is usually the same dimension as the pit top; therefore, it is not physically possible to install to slope as designed.
- Install the kerb block support exactly to position and shape, with high standard smooth and neat insitu concrete surfaces, necessary to prevent clogging.
- Insitu concrete should be durable for "service life" so that it will not disintegrate with time and clog the throat of the opening.

Figure 14: Standard Splay Catchpit Detail (NSCC 2009)



Auckland North Shore City Council Splay Pits (Figure 14) are another example where incorrect construction practices make long term clogging more likely. Water flow path from kerb opening is determined by a cast insitu concrete slab that should be constructed with the following points in mind to avoid clogging:

- Top of the sump should be installed exactly to position and to the correct level during the early construction stages to achieve the design fall.
- The design fall of 25mm represent less than 1.5% grade, any loss in this small grade will cause water ponding and accumulation of debris which may cause full clogging.
- If the road fall is more than 1.5%, then achieving flow upstream from the downstream opening requires constructor to modify design on site to achieve acceptable fall.
- Insitu concrete slab should be smooth and true to line so that it will be self cleaning, and not subject to clogging.
- The quality of concrete and thickness of slab should be controlled so that it will not disintegrate with time, or allow weed growth, and hence become totally clogged.

- Slope of channel and height of kerb opening should be constructed as per design; otherwise any loss in the height of the opening may make it more prone to clogging during service.

3.3 ROAD RESURFACING AND CATCHPIT CAPACITY

Catchpit and sump capacity and designs are rarely considered during road resurfacing construction; below is some of the road resurfacing practices which are believed to affect performance of inlets compared to the original designs:

- Surfacing on top of the approaching channels which completely change the hydraulic characteristics of the kerb and channel – inlet systems.
- Adding asphalt layer around the inlet apron without any adjustment to grate position, concrete surround, and apron – channel merger.
- Reduction in the height of kerb relative to level of the road surface significantly reduces the maximum quantity of approaching water, and affects the design balance of numbers and spacing of catchpits.

3.4 SAFETY AND CAPACITY

Measures to increase the capacity of existing inlets are some times taken without considering the effect on the safety of vehicles, cyclists, and other road users. Below are some such practices that were observed in Auckland roads:

- Further depression of the grates and apron, and/or lift the opening top slab to increase the height of kerb openings. Standards usually call for a kerb opening not more than 125mm height so that a high flow of water will not suck a baby or a small dog into the drain. This limit may have been breached in some cases without installation of protective bars or grates.
- Further depression of the grates without a proper concrete apron to merge this depressed area with the rest of the road. This represents a serious hazard for both vehicles and cyclist especially during heavy storms, when all road sides are covered with water.
- Making a small concrete dam on the channel downstream inlets on steep roads. Such practices have created a clear hazard to all road users.

4 CONCLUSIONS

The following conclusions are drawn from the results of the investigation:

1. Correct calculation of capacity of catchpits and sumps during road design stages requires the road owners to specify the design parameters and requirements, including, and not limited to, width of spread and design storms, otherwise designs may not satisfy expectations.

2. Inlet and gutter geometry have a significant effect on the design capacity of catchpits and sumps, designers should specify all geometry parameters and ensure that they can be achieved during construction, to get reliable results.

3. Grate size and design is an important input factor in calculating inlet capacities, hydraulic rating of grates used in New Zealand represents one of the main missing information areas required for proper design.

4. Highly skilled construction people and continuous supervision is required to build catchpits exactly as per design, and maintain high quality construction. Poor quality construction affects capacity, makes clogging probable and may affect safety of road users.

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