UNIVERSITY OF LIEGE
FACULTY OF APPLIED SCIENCE

Analysis of clogging of bridges during Liège 2021 flood events

Thesis for a Master of Science in Civil Engineering specialized in Urban and Environmental engineering by Gianni MASSIN

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Résumé

Etudiant: Gianni Massin Promoteur: Benjamin Dewals Année académique 2022-2023

Analyse de la formation d'embâcle des ponts lors des inondations de 2021 en province de Liège

Faculté de science appliquée : Master en ingénierie urbaine et environnementale

Les inondations désastreuses de Juillet 2021 en Belgique ont causé d'énormes dégâts. Certains de ces dégâts ont été causés par l'accumulation de débris au niveau des ponts. Ces embâcles sont étudiés dans le cadre de ce mémoire afin de déterminer quelles sont les caractéristiques, tant d'un point de vue paramètres structuraux des ponts que d'un point de vue hydraulique, causant de larges volumes d'embâcles.

Ce mémoire commence par expliquer quels sont les paramètres qui ont être étudiés, en les définissant. Il apporte la méthodologie suivie ainsi que le système d'encodage effectué pour récupérer les données. Une évaluation critique de la fiabilité des résultats est donnée.

L'analyse des résultats généraux débute ensuite sur base des données récoltées sur les ponts ayant créé et n'ayant pas créé d'embâcle. Une étude de ces paramètres permet de déterminer s'il vaut la peine, ou non, de poursuivre sur des analyses plus poussées les concernant.

Lorsque les paramètres semblant déterminants ont été choisis, des analyses poussées les liant au volume d'embâcle sont effectuées afin de voir quels sont les paramètres impactant le plus la formation d'embâcle. Ce mémoire suggère que le nombre de piles, la distance entre celles-ci et la hauteur d'eau vis-à-vis de la hauteur du tablier de pont sont les paramètres les plus influents sur la formation d'embâcle.

Le mémoire poursuit alors en avançant que ces paramètres influents sont communs entre les ponts ayant créés de gros volumes d'embâcle mais sont aussi des paramètres qui ne sont pas retrouvés parmi les ponts ayant accumulé le moins de débris.

Une conclusion générale est alors apportée, rappelant les paramètres n'ayant que peu d'influence et ceux déterminants.

Summary

Student: Gianni Massin Promoter: Benjamin Dewals Academic year 2022-2023

Analysis of the clogging of bridges during Liège 2021 flood events
Faculty of applied science : Master in Urban and Environmental Engineering

In July of 2021, Belgium faced critical floodings causing a lot of damages. One of the reason was the clogging of bridges which obstruated the main flow of the rivers, preventing them from following their natural path. This Master thesis studies the structural parameters of the bridges along the Vesdre river that could be the cause of the cloggings. It puts in relations those parameters with hydraulical ones and establish which parameters have an influence on the amount of volume of debris clogged.

This Master thesis starts by generalizing the data used to make the analyses. It defines the important parameters to consider and explain the methodologies followed to gather the data. At the end of this chapter, a fiability assessment is given in order to determine which data is trustful or not.

The Master thesis follows by analysing the main characteristics of the bridges, differentiating the ones that caused cloggings and the other ones. This section allows to select parameters that seem more important and need to be analysed precisely in comparison with other parameters.

The main part of the thesis consists in comparing the different parameters judged relevant with the amount of volume that was clogged by a bridge. Different graphs are made trying to find correlations between parameters and volume. At the end of this chapter, the amount of piles, the distance between the piles, the shape of the deck of the bridge and the water height are judged as the most influent parameters on cloggings.

The last part of this master thesis convince that the parameters listed above are the most influent on cloggings by finding common characteristics between the bridges that caused cloggings of high volumes and by proving that those characteristics differ from the bridges that didn't cause any cloggings. It explains the situation that happened in Verviers during the floodings.

The Master thesis concludes then on the importance of those parameters while reminding the other parameters studied that didn't have a major impact on the cloggings.

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Chapter 1

Introduction

In July 2021, Belgium suffered from historical floods which damaged a huge part of the province of Liège. A part of the responsabilities are given to the bridges that accumulated large amount of debris, causing a blockage of the flow. This Master thesis aims to determine whichs parameters are the most influent on the forming of cloggings. tructural parameters of the bridges are studied as well as hydraulical ones coming from the available data in order to quantify their influence on the accumulation of debris. This Master thesis will focus on the Vesdre river but will also take information of the floods of the Hoëgne and of the Helle rivers.

The Master thesis starts by introducing the parameters that are studied in this project by defining them rigourosly in the form of a lexicon. It advocates the reasons to study those parameters and to analyse them. It explains the principle of the database which was created in order to collect and use the data easily. The methodology of that encoding is explained in details with practicle examples. The methodology is made to allow other users to understand how to encode the database. A fiability assessment is given about that encoding, explaining how the data registered can be found.

The main content of the Master thesis is divided in three categories. The first one is the analysis of the general data encoded. The main characteristics of the bridges studied are displayed using graphs and first deductions of the important parameters are made based on the structure of the bridge and if it caused a clogging or not. Some parameters are judged irrelevant for the rest of the project and an explaination is given on why it isn't necessary to study them. A motivation to analyse further other parameters is given.

The following section of the thesis consists in analysing precisely the parameters among each other, particularly in correlation with volumes of debris. As this is the main characteristic of cloggings, the volume of debris is compared to every other parameter to see if those had an influence on it or not. Multiple graphs are shown in order to prove the importance and influence of the parameters on the volume of debris. A conclusion is made on the parameters that look the most important regarding floodings.

Deeper analyses are made about the few parameters that are judged as the most dominant on accumulation of debris. A distinction between the bridges that created the most volumes of debris and the bridges that didn't cause any cloggings is made thanks to these parameters. This final section proves the effect of those parameters on cloggings and show that the bridges that caused the cloggings share the same characteristics, while the bridges that were not problematic in the floodings are proven not to have those characteristics. A practical example is made using the municipality of Verviers.

Finally, a general conclusion gives the parameters that are judged dominant on the forming of cloggings while reminding the other parameters which were not as important.

Chapter 2

Database

This chapter presents the different elements forming the database, what is studied and why, and the methodology used to encode it. It concludes with the fiability of that encoding.

A first section will define the parameters who are studied and required for the encoding of the database and associate them with a quick explanation when necessary to guarantee the complete understanding. A motivation of those parameters will be given to justify the interest of having them in the database. This section will serve as lexicon. The next section will present the methodology followed to encode each parameter in the database by giving a concrete example in details. It will also present the alternate methodologies that can be followed when the main methodology is not possible to apply. The final section will assess the fiability of the encoding, helping the user on how to determine which information can be used as precise or not. Clear definitions of degrees of precision will be given in that section. This step is essential to be able to further interpret the analysis encoded in the database.

1 Lexicon

The elements listed below are the ones forming the database, representing each an Excel column of an Excel sheet named "DataBaseStructures" which is used to encode the data.

1.1 Encoding part

The encoding part is used to know who is in charge of the encoding and when it was done. It associates a structure with an ID in order to easily navigate through the database.
ID [#]: Identification number of the structure. For consistency in the database, the ID ranges to follow are 10000 to 19999 for RWTH, 20000 to 29999 for TUDelft and 30000 to 39999 for ULiège.
Institution: Name of the institution encoding the id. The database only allows those possible answers : RWTH, TUDelft and ULiège.
Encoder's name: Name of the encoder.
Date [DD/MM/YYYY]: Date of the encoding in the [DD/MM/YYYY] unit.

1.2 Location part

The location part is used to easily locate the position of the structure. It must provide enough data to be able to locate the structure on conventionnal mapping websites or softwares. It adds general information about the structure and the river studied.

Type of structure: Type of the structure considered. The database only allows those possible answers : bridge, culvert, building, deposit on the bank and railway bridge. In this project, only bridges and railway bridges were analysed. Railway bridges show major differences in comparison to common bridges, such as a much greater elevation above the river bed and wider piles. It can result in different ways of cloggings than for more common bridges as the piles are most of the time the dominant factor. This is the reason why they are distinct choices in the database.
Year of construction [YYYY]: Year when the structure was commissioned. It can be an interesting factor to study to see if there is a correlation between age of the structure and cloggings or damages.
River: Name of the river responsible for the floods.
Municipality: Name of the municipality where the structure is located.
Structure / street name: Name of the structure or name of the street where the structure is located.
EPSG: EPSG ID of the coordinate reference system used.
X reg: Coordinate X of the regional projected system used. The centre of mass of the footprint of the structure is taken as reference.
Y reg: Coordinate Y of the regional projected system used. The centre of mass of the footprint of the structure is taken as reference.
Lat [° ' '']: Exact latitude in [° ' ''] unit. The centre of mass of the footprint of the structure is taken as reference.
Long [° ' '']: Exact longitude in [° ' ''] unit. The centre of mass of the footprint of the structure is taken as reference.
Curvilinear abscissa [m]: Position of the structure based on its curvilinear abscissa along the river, in meter [m] units. The origin is the upstream of the river (spring). It can be useful to evaluate the real distances between bridges.
River bed elevation [m]: Lowest elevation of the river bed at the structure. This parameters will be used to determine the water depth during the events, which is a crucial factor in floodings.
Upstream river shape: Shape of the river upstream the structure. The database only allows those possible answers :

- Straight: The shape of the river bed upstream the structure is straight. The shape is straight if it is possible to go to upstream by a distance of 5 times the width of the river, from the upstream middle of the structure, in a perpendicular direction to the river cross section, without reaching a bank of the river.

- Curved right: The shape of the rived bed upstream the structure is curving to the right. The shape is curved right if while going to upstream by a distance of maximum 5 times the width of the river, from the upstream middle of the structure, in a perpendicular direction to the river cross section, the left bank is reached.
- Curved left: The shape of the rived bed upstream the structure is curving to the left. The shape is curved left if while going to upstream by a distance of maximum 5 times the width of the river from the upstream middle of the structure, in a perpendicular direction to the river cross section, the right bank is reached

This parameter will be studied to determine if a correlation exists between the shape of the river upstream the structure and the location of the debris at the structure. Figure 2.1 explains visually what the upstream river shapes can look like.

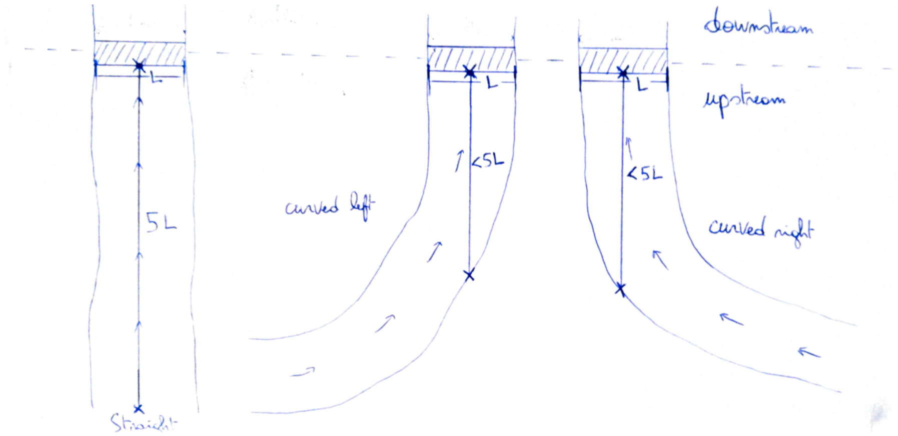

Figure 2.1: Upstream river shape explanation

1.3 Structure part

This part of the database focuses on the structural data of the bridges. It is fundamental to be able to differentiate the bridges based on their structural elements to know which ones may be the dominant causes of the cloggings.

Opening(s) shape: Opening shape of the bridge deck. The database only allows those possible answers : rectangular and arched. Non exhaustive examples rectangular and arched opening shapes are shown below in figures 2.2 and 2.3

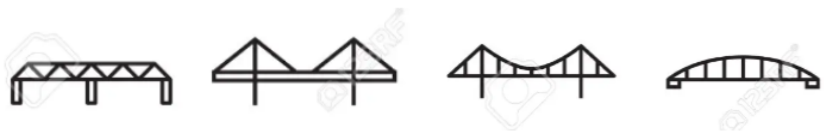
Figure 2.2: Examples of rectangular opening shape

The idea of this parameter is to know if the shape of the bridge deck can be a source of clogging or not.

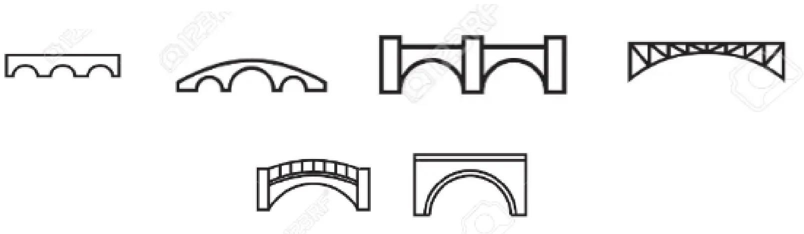

Figure 2.3: Examples of arched opening shape

Width [m]: Width of the structure, in meter [m] unit. The measurement is taken in a perpendicular axis to the length of the structure, independent from the river flow orientation.
Length [m]: Length of the structure, in meter [m] unit. The measurement is taken from an orthogonal axis to the width of the structure, independent from the river flow orientation. Length of the bridge is an important factor to analyse as the debris often accumulate along the length of the bridge.
Slope [%]: Slope of the structure, in percentage [%] unit. The start of measurement is taken on the right bank side of the structure. Positive value if the left bank side is more elevated than the right bank side, negative value if the left bank side is below the altitude of the right bank side.
Angle [°]: Angle of the structure with the river section, in [°] units. The angle is measured between the axis made by the river section perpendicular to the river flow and the axis parallel to the length of the structure, both going through the centre of the structure. The beginning of measurement is taken on the left bank. Positive value from 0° to 90° in the clockwise direction. Negative value from 0° to -90° in the anti-clockwise direction. Figure 2.4 shows visually how the angle is calculated.
Thickness [m]: Thickness of the structure, in meter [m] unit. If opening shape is arched, thickness is taken at the top of the arch, where the thickness is the lowest.
Altitude on the bridge [m]: Altitude of surface on the deck of the bridge/structure, in meter unit [m], taken at the centre of mass of the footprint of the structure. This information allows us to determine the height above the river bed and wil be useful for water depth calculations.
Form river section: Form of the river bed section. The database only allows those possible answers :

- Regular: The river bed section has a regular shape, i.e. the altitude of the river bed is relatively constant or has an expected / symmetric shape.
- Unregular: The river bed section has an unregular shape, i.e. the altitude of the river is not relatively constant and varying in an unexpected way.

Unregularities might play a role in the accumulation of debris as it can reduce the height above the river bed on certain points of the river section.
Nb of piles [#]: Number of piles in the river. The abutments are not considered as piles. Piles can play a role in the accumulation of debris as they are obstruating the flow.

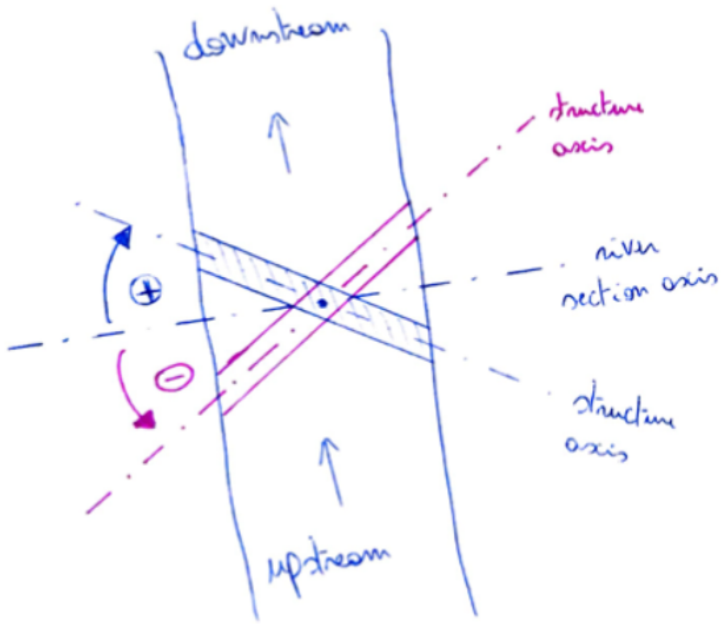

Figure 2.4: Angle of the structure

Piles width [m]: Width of the piles, in meter [m] unit. If piles don't have the same width, the maximum width is taken.

Distance between piles [m]: Distance between the piles, in meter [m] unit. The measurement always starts at the extremity of the width of the pile. If the location of the debris at the structure is concentrated on a single span between the piles, the distance between the piles is that span where the debris were accumulated during the event (i.e. for example, left bank debris accumulation would require an encoding of the distance between the left bank and the left pile or centre pile in the case of a one pile bridge). If it is not clear that the debris accumulated precisely on a span between piles, the smallest distance between the piles is taken. If no pile, the length of the bridge is taken. Distance between piles is a major factor to analyse as it is usually thought that the lower the distance, the higher the probability of long debris to accumulate. This project will try to confirm or infirm that thought.

Piles shape: Shape of the piles. The database only allows the possible answers : circular, round nosed, square nosed sharp nosed or no pile. Figure 2.5 shows the different shapes.
The shape of the pile might increase or decrease the probability of clogging.

Piles protrusion [m]: Length of the protrusion of the piles, in meter [m] unit. This parameter will help us to see if the protrusion can reduce the amount of debris or not.

Id photo bridge: ID of the photos that can be useful to understand the dimensions and characteristics of the structure listed above. Each photo has a single ID number depending on the institution completing the Excel sheet : 100000 to 199999 for RWTH, 200000 to 299999 for TUDelft and 300000 to 399999 for ULiege. If multiple photos, the ID can be separated by a comma. The ID directly refer to an Excel sheet 'DataBasePhoto' which attributes the link of the useful photos to their ID.

Handrail material: Material of the handrail. The database only allows the possible answers

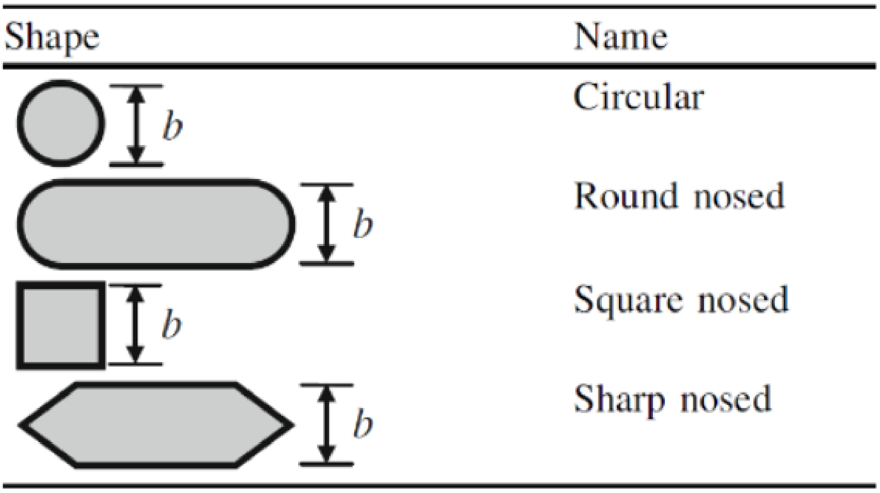

Figure 2.5: Shapes of the piles considered (Author: B. Dewals

: stones, metal, mix or other. Mix means a combination of stones and metal. The material type could be a reason of the damage of the handrails

Handrail height [m]: Height of the handrail, in meter [m] unit. As the handrails gets taller, the surface obstruating the flow increases, which can increase the probability of clogging.

Handrail porosity: Porosity of the handrail. The database only allows those possible answers

- Total: The porosity is considered total when there is no handrail.
- High: The porosity of a handrail is considered high when it has spaced elements that are vertical, horizontal, a combinaison of the two latest or forming a cross of Saint André. Figures **??**, 2.11 and 2.7 are examples of high porosity on bridges studied in the database.
- Medium: The porosity of a handrail is considered medium when the handrails are composed of patterns or thick barriers for around 50% of the handrail or when multi-directional elements are not spaced. Figures 2.8, 2.13 and 2.9 are examples of medium porosity on bridges studied in the database.
- Low porosity: The porosity of a handrail his considered low when the whole handrail has large barriers or if it doesn't allow the water to go through it on 75% or more of its surface. Figures 2.10, 2.12 are examples of low porosity on bridges studied in the database.
- No porosity: The handrail is a continuous wall.

It is likely that a handrail with low porosity has greater chances of causing accumulation of debris. This study will try to prove if this idea is true or not.

Id photo handrail: Id of the photos that can be useful to understand the information of the handrail listed above. Similar way to encode than ID photo bridge.

Figure 2.6: High porosity : Spaced vertical elements

Figure 2.7: High porosity : Spaced horizontal elements

Figure 2.8: Medium porosity : Patterns

Figure 2.9: Medium porosity : Half patterns

Figure 2.10: Low porosity handrail : thick elements

Figure 2.11: High porosity : Cross Saint André

Figure 2.12: Low porosity handrail : large barrier

Figure 2.13: Medium porosity : Multi-directional elements

Structure damage: Damage affecting the structure during flood events. The database only allows those possible answers :

- No: No damage affected the bridge.
- Slightly: The structure is slightly damaged. Slight damages are observed with slight deformation of handrails, when some pavements of the road are missing, when slight parts of the road are damaged but without the serviceability nor the stability of the structure being impacted.
- Partly: The structure is partly damaged. Partial damages are observed when the handrail is partly broken in multiple places, when multiple pavements or parts of the road have been damaged but without the serviceability nor the stability of the structure being impacted.
- Strongly: The structure is strongly damaged. Strong damages are observed when the entire handrail is broken, when the pavements or parts of the road are missing to the point that the serviceability is impacted but not the stability.
- Completely: The structure is completely damaged. The structure is destroyed, unserviceable and unstable.

This will help to know which kind of bridges have been damaged and if some bridges are naturally more subjected to be damaged than others. Relations between damage and kind of debris or hydraulic parameters will be made.

1.4 Flood event at the structure

This part of the database focuses on the hydraulic parameters that happened during the flood at the structure. In case of clogging, it is important to know those parameters and see if they have had any influence on the clogging or not.

Flood event: Name of the event of the flood.
Max water level [m]: Maximal water surface elevation during flood events, in meter [m] unit.
Type of flow: Type of flow at the structure. The database only allows those possible answers:

- Free surface: The flow during the flood event was of free surface. The water depth was below the lowest elevated part of the thickness of the structure.
- Pressurized: The flow during the flood event was pressurized. The water depth was at the level of the thickness of the structure, i.e. higher than the lowest elevated part but lower than the highest elevated part of the thickness of the structure.
- Mixed: The flow during the flood event was pressurized. The water depth was above the highest elevated part of the thickness of the structure.

This information is really important. When the flow is mixed, the bridge is under the maximal water level and the deck is then directly in contact with the water, meaning that it can obstruct debris. When the flow is of free surface, the deck thickness of the bridge doesn't play a role in the accumulation of debris, meaning that other parameters should be responsible for the clogging. Figure 2.14 gives a visual representation of the different types of flow.

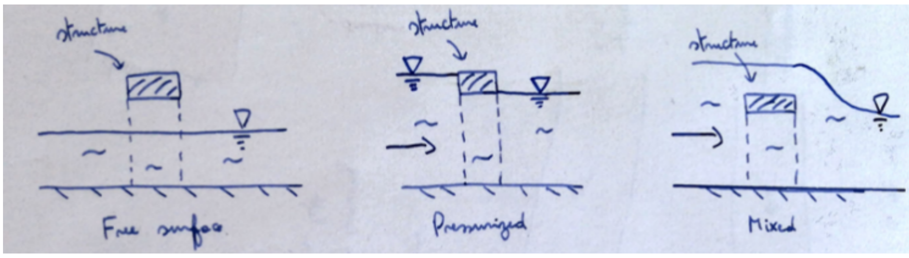

Figure 2.14: Different flow types studied

Discharge [m^3/s]: Maximal discharge evaluated at the structure, in cubic meters per second [m^3/s] unit. might help know if debris tend to accumulate in larger volumes when greater discharges happen or not.
Max water depth [m]: Maximal water depth at the structure, in meter [m] unit. It is the difference between max water level and river bed elevation. This parameter is crucial as large water depths could potentially increase the amount of debris accumulated.
Flow width [m]: Width of the flow during the events, in meter [m] unit.

1.5 Deposit part

Clogging ?: Confirms the presence of a clogging or not of the bridge. A clogging is defined by any accumulation of debris at the bridge. The database only allows those possible answers :

- Yes: We know for sure a clogging appeared at the structure.
- No: We know for sure a clogging didn't appear at the structure.
- No information: We don't know if there was a clogging at the structure.

Total length [m]: Maximal length of the clogging of the structure, in meter [m] unit. Orthogonal axis of the width of the river. The residual debris that are not part of the carpet are taken into account in this length measurement, meaning that the length of a debris on the top of the bridge is measured.
Total width [m]: Total width observed of the clogging of the structure, in meter [m] unit. Same axis as the width of the river. The residual debris that are not part of the carpet are taken into account in this width measurement, meaning that the width of a debris on the top of the bridge is measured. If debris are accumulated at different parts along the length of the bridge, the widths of those debris are added and taken into account in the total width. Figure **??** helps understand how the total width and total length are measured.
Total height [m]: Maximal height observed of the clogging of the structure, in meter [m] unit. This measurement takes into account the top of any debris accumulated at the bridge.

Volume [m^3]: Estimation of the global volume of clogging of the structure, in cubic meter [m^3] unit. This parameter will be used to see which bridges accumulated more volume of debris to further know which structural and hydraulic parameters are causing significant accumulations of volume of debris.
Carpet ?: Confirms the presence of a carpet or not among the clogging. A carpet is defined by a consistent accumulation of debris along a certain part of the bridge. Debris located on the top of the bridge are not taken into account. The database only allows those possible answers :

- Yes: We know for sure a carpet was part of the clogging.
- No: We know for sure a carpet was not part of the clogging.
- No information: We don't know if there was a carpet.
- Pile carpet: The carpet only accumulates on the piles of the bridge.

This parameter is interesting to study in order to differentiate the clogging made of inconsistent accumulation of debris and other ones made of a consistent carpet. Pile carpet is an interesting scenario of carpet clogging which has his own category as it is not similar to the other ones. The specific case of carpets accumulated on multiple piles and forming distinct carpets is showcased in figure 2.15.
Carpet length [m]: Maximal length of the carpet, in meter [m] unit. Orthogonal axis of the width of the river. The residual debris that are not part of the carpet are not taken into account in this length measurement. If multiple pile carpets, only the greater length of those carpets is considered.
Carpet width [m]: Maximal width of the carpet, in meter [m] unit. Same axis as the width of the river. The residual debris that are not part of the carpet are not taken into account in this width measurement. If multiple pile carpets, only the greater width of those carpets is considered.
Carpet height [m]: Maximal height observed of the carpet, in meter [m] unit. The residual debris that are not part of the carpet are not taken into account in this height measurement.

- Total length - left case : from y1 to y4
- Total length - right case : from y1 to y2 + y3 to y4
- Carpet length - left case : from y2 to y4
- Carpet length - right case : from y3 to y4
- Total width - left case : from x1 to x2 + x3 to x5
- Total width - right case : from x1 to x2 + x3 to x4
- Carpet width - left case : from x1 to x2
- Carpet width - right case : from x1 to x2

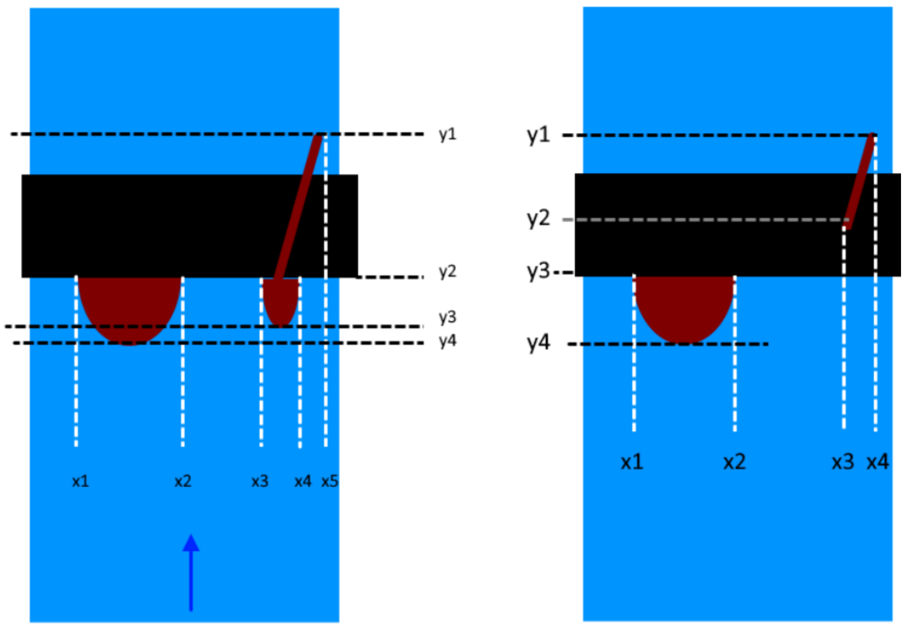

Figure 2.15: Examples of piles carpet and clogging (Author: D. Poppema

Carpet surface [m^2]: Surface of the carpet, in squared meters [m^2] unit. This parameter allows to understand the surface blocked upstream by the bridge, focusing only on the consistent carpet of debris. It will also be linked with carpet length and carpet width to determine shapes of the cloggings.
Carpet volume [m^3]: Volume of the carpet, in cubic meters [m^3] unit. This parameter helps understand the part of the carpet in the complete clogging as well as calculating a mean height carpet value based on the surface.
Location at structure: Estimation of the location of the clogging at the structure. The database only allows those possible answers:

- Right bank: The clogging occurs on the right bank of the river.
- Center: The clogging occurs on the center of the river.
- Left bank: The clogging occurs on the left bank of the river.
- Piles: The clogging only occurs on the piles of the structure.
- Whole width: The clogging occurs on at least 80% of the width of the river.
- Handrail: The clogging is essentially stuck on the handrails of the structure.

This parameter will be linked with the upstream river shape to know if a correlation exist between the two.
Id photo deposit: Id of the photos that can be useful to understand the estimations of the deposit. Similar way to encode than ID photo bridge.

1.6 Main debris part

This part focuses on the debris accumulated giving information about their type and their percentage among the clogging.

Main trunk ?: Confirms the presence or not of a main trunk as potential cause of the clogging. The database only allows those possible answers :

- Yes: We know for sure a trunk is causing the clogging.
- No: We know for sure a trunk is not causing the clogging.
- No information: We don't know if there is a trunk as a cause of the clogging.

Id main type: Refers to the Id of the main types of debris observed in the total deposit. Id main type 1, 2 and 3 respectively represent the first, second and third main types of debris in volume percentage observed in the total deposit. The information about those Id can be found in the Excel sheet 'DataBaseDebris'.

Volume percentage [%]: Estimation of the volume percentage of the main, second and third types of debris in the total deposit.

1.7 DataBaseDebris Excel sheet

The DataBaseDebris Excel sheet summarizes the different types of debris that are likely to be present in the deposit. For a given type of debris, general information about material, length, height and the fraction length/height is given, trying to represent a classical single type of debris. Figure 2.16 explains how those informations were used in the database.

	A	B	C	D	E	F
1	Id_debris	Type_floating_debris	Material_floating_debris	Length_floating_debris	Height_or_diameter_floating_debris	Length/height_floating_debris
2	10	Natural wood	Wood	12	0,6	20,00
3	11	Antropic wood	Wood	10	0,4	25,00
4	12	Container	Plastic	1,5	1	1,50
5	13	Container	Metal	5	2	2,50
6	14	Vehicle	Various	5	1,5	3,33
7	15	Household items	Various			
8	16	Industry items	Plastic, metal			
9	17	Tanks	metal			
10	18	Other				

Figure 2.16: Additionnal excel sheet complementing debris data

2 Methodology

The present methodology describes the different methods that were used to encode the parameters of the database. It illustrates how those methods could be used by using practical examples. Alternate methodologies are also presented when the main one was not possible to use on some particular bridges.

2.1 Main methodologies

2.1.1 WalOnMap

WalOnMap was the main tool used to encode the location part. By following the Vesdre river, it was easy to localize the bridges and discovers the location information as it is directly given by the website using its information tool. The parameters Type of structure, River, Municipality, Structure / street name, X reg, Y reg, Lat, Long were all defined by using WalOnMap. Figure 2.17 shows the information about the bridge Francval, located in Verviers.

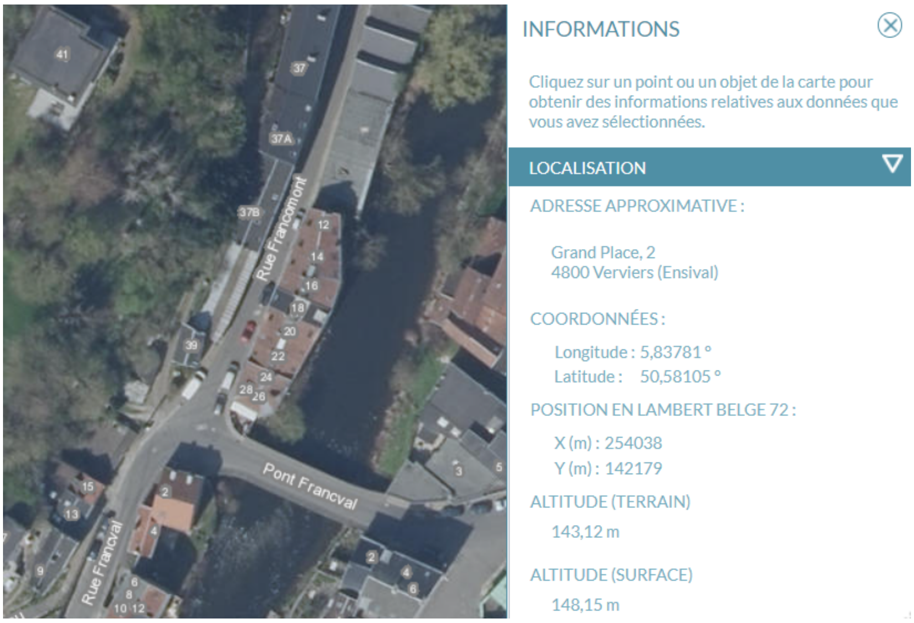

Figure 2.17: Location information of the bridge Francval in Verviers

WalOnMap was also used when trying to know the upstream river shape. It has the ability to measure a distance on the map, making it easy to evaluate which condition of upstream river shape there is. Figure 2.18 shows that the bridge Francval has a curved right upstream shape (5L is higher than the measurement taken).

A third and last useful way to use WalOnMap was when trying to calculate the angle. WalOnMap makes it possibles to trace lines remaining on the map. By doing so, it is possible to trace the axis of the river and the axis of the bridge. After that, it is easy to calculate the angle between the two lines. Figure 2.19 shows that the angle of bridge Francval with the river is around -1°.

2.1.2 Plans

Plans were a major source of information about the structural part. Most of the data were directly found on them. Figure 2.20 shows the plan of the bridge Francval.

Figure 2.18: Upstream river shape of Bridge Francval

Figure 2.19: Angle of the bridge Francval calculated using WalOnMap

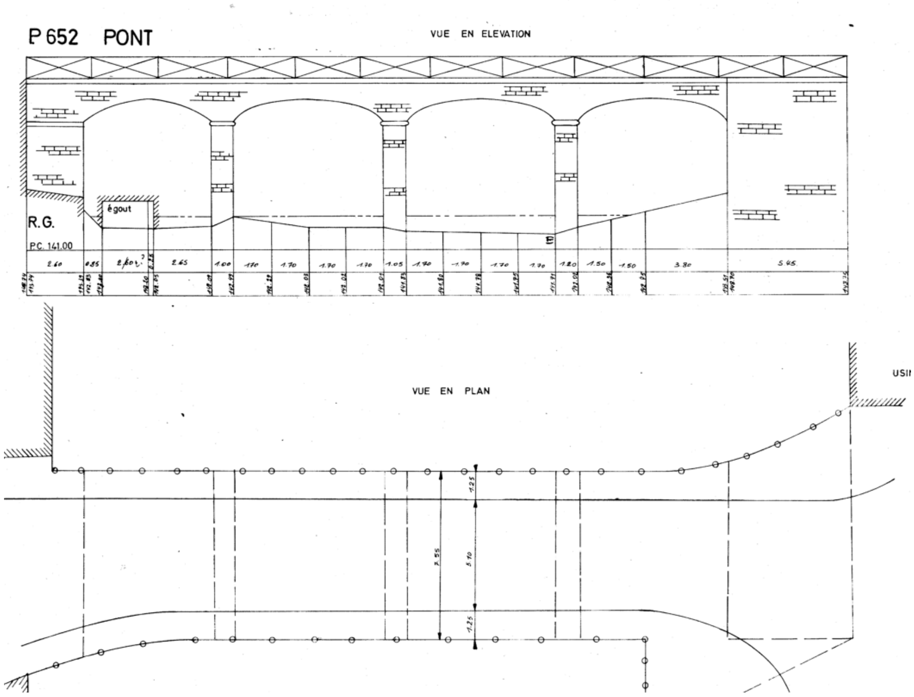

Figure 2.20: Plan of the bridge Francval

2.1.3 QGis

QGis was really useful to determine the curvilinear abscissa of the bridges along the river. It is possible to download shapefiles of the river from WalOnMap or OpenStreetMap and also to reference the location of the bridges directly on it based on the X reg and Y reg coordinates. After that, it is possible to create polylines of the river and seperate these lines between segments of a certain distance. As the beginning of the river is starting upstream, QGis understand by default that the distance 0 comes from the most upstream point of the river. It is then possible to evaluate the distance of the different points from the most upstream position. Figures 2.21 ans 2.22 show the location of the bridges on the rivers using QGis.

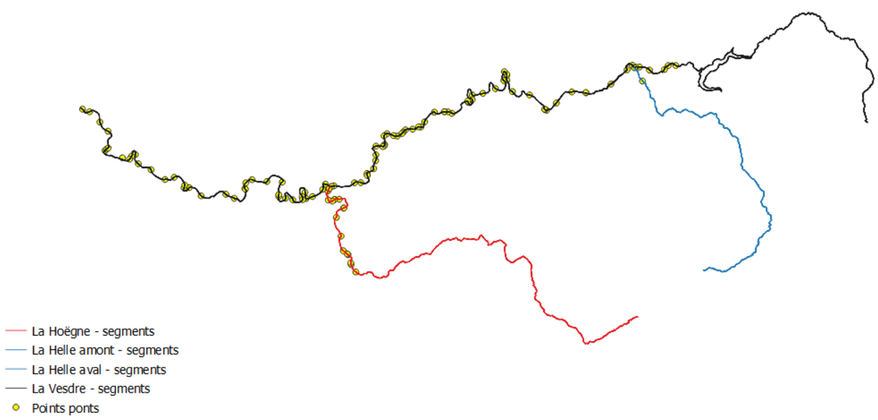

Figure 2.21: Location on the bridges along the rivers studied

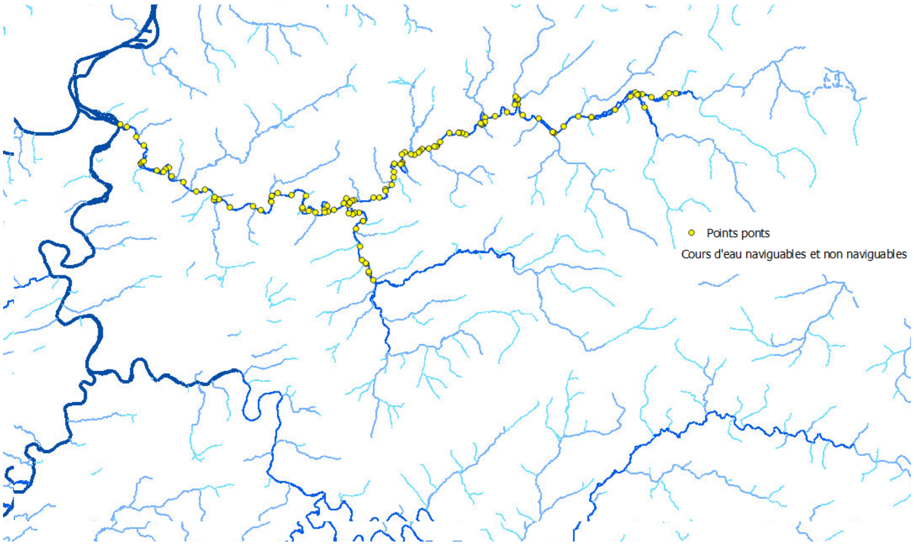

Figure 2.22: Location on the bridges along all of the rivers

2.2 SPW surveys

After the flood events of July, the SPW "Service Public de Wallonie" lead a number of surveys along the Vesdre river in order to catch measurements of the water heights. Those water heights were measured on houses that kept a trace of the water level on their walls. The X reg and Y reg coordinates of those houses were given in addition to the water height and the data could then be used to estimate the max water level. These surveys were obviously also used to calculate the max water depth.

2.3 Photos analysis

The documentation about the clogging of bridges is essentially coming from photo that were taken a short time after the events and made available to the public. These photos allowed to estimate precisely the quantity of debris thanks to Imagej.

Imagej is a software able to measure the distances between two points on a picture, based on a pixel distance, assuming a reference measurement is known on the picture. This software was used to determine the length, width and volume of the debris based on photos showing the acucmulation of debris on the bridges that we are studying. Most of the time, an aerial photo was taken for the use of imagej in order to have a vertical view, ensuring that the pixel measurement was close to the reality, while a close photo of the clogging was used to estimate points of comparisons. The procedure was to use an general image from WalOnMap and generate a reference measurement of this image on Imagej. After that, a surface of the estimated clogging or carpet was traced and the area automatically calculated. Width and length were calculated based on this surface shape and volume was estimated with an estimation of the average height. Figures 2.24 and 2.25 show this procedure for the bridge Francval. The photo showing the real clogging is in figure 2.23.

Figure 2.23: Real clogging of the bridge francval

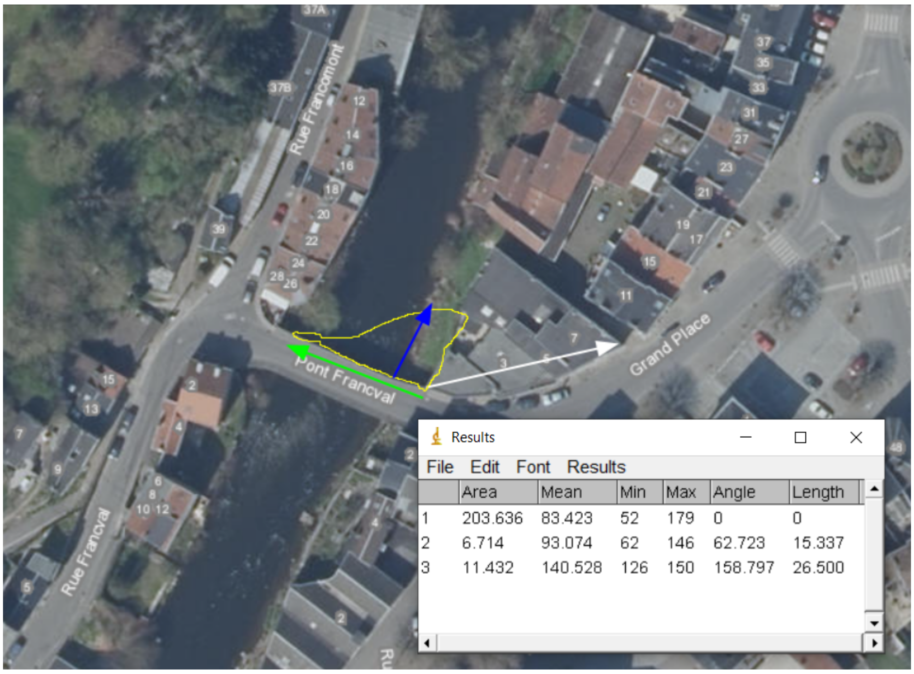

Figure 2.24: Use of imagej to determine the length, width and surface of the clogging of bridge Francval

2.4 ULiege reports

The university of Liège provided a complete analysis of the hydraulic events occuring during the flood events in Liège. These reports were used to estimate the discharge.

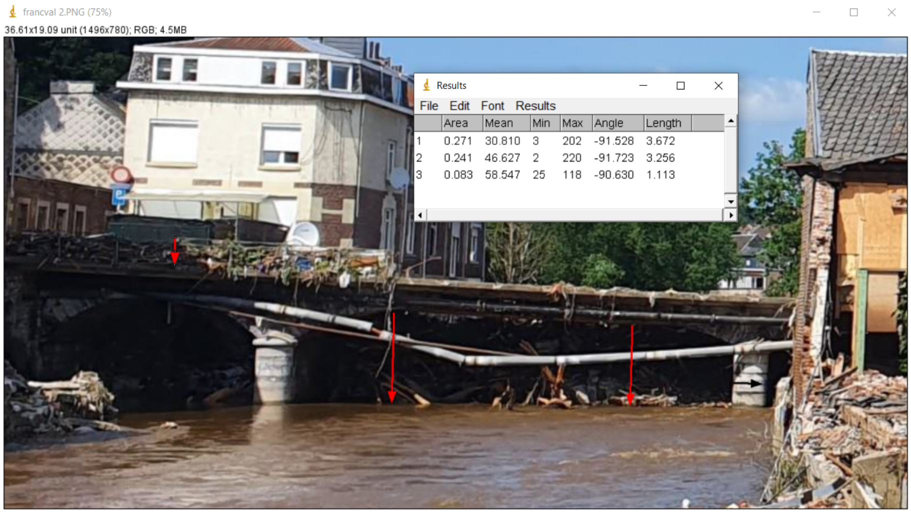

Figure 2.25: Use of imagej to determine the height of the clogging of bridge Francval

2.5 Alternative methodologies

2.5.1 WalOnMap

WalOnMap was also really useful when trying to calculate measurements which usually were known by looking at an official plan when there wasn't such a plan available. The altitude on the bridge is given directly at the same moment as the location information as seen in figure 2.17. It was also a tool helping measuring distances as length, width, distance between piles when there was no plan of the bridge available. The altimetry measurement of WalOnMap would also help having an approximation of the slope and the form open section.

2.5.2 On site visit

A visit of all the bridges was done to harvest additionnal data on the bridges. The visits were taken on 27/11/2022 and 30/11/2022 and allowed to confirm the measurements of the thickness, handrail height and piles protrusion when it was possible. It helped have more or less accurate data on the bridges that lacked dimensions on the plans or didn't have any plans at all. Even more than one year after the events, the visits were giving new informations about structure damage.

3 Fiability

The present assessment is a guideline to follow to estimate the fiability of the database. The fiability is divided in categories represented by a number to describe the precision of the encoding : the lower the number, the higher the precision. The added colours are used to suggest consistent colours for the graphs that will be generated during the analysis. Many parameters are following the same rules of fiability as the methodology to encode them in the database is the same. Those parameters will be regrouped and share the same categories of precision. The parameters that are not directly refering to a value or an information about the structure don't have a fiability guideline. Those parameters are Id, Encoder's name, Date, EPSG, Id photo bridge, Id photo handrail, Flood events and Id photo deposit. As similar database could be used by other people, the fiability of some different methodologies than the ones explained on section 2 are presented.

3.1 Location part

Type of structure, River, Municipality, Structure / street name, X reg, Y reg, Lat, Long

1 : Exact information or value (blue): A confident way to localise the structure such as Google Maps, WalonMap or a software like QGIS was used to determine those location parameters, leading to no doubt of the encoding.
2 : Doubtful information or value (orange) : The structure was not localised correctly, leading to a doubtful encoding.

Year of construction

1 : Exact value (blue): The year of construction is perfectly known thanks to official data.
2 : Imprecise value (yellow): The year of construction is not exactly known but is guessed using external ressources that might not be accurate.

Curvilinear abscissa

1 : Precise value (green): The curvilinear abscissa was precisely calculated using a precise software such as QGIS or similar which is able to use the data from a river and calculate the distance from upstream to downstream by segments of maximum 10 meters.
2 : Slightly imprecise value (yellow):The curvilinear abscissa was calculated using a precise software such as QGIS or similar which is able to use the data from a river and calculate the distance from upstream to downstream by segments of maximum 50 meters.
3 : Imprecise value (orange): The curvilinear abscissa was calculated using a precise software such as QGIS or similar which is able to use the data from a river and calculate the distance from upstream to downstream by segments of maximum 200 meters.
4 : Very imprecise value (red): The curvilinear abscissa was not calculated using a precise software but by estimations of distances instead.

River ber elevation

1 : Exact value (blue). The river bed altitude is found directly on plan or using bathymetry measure.
2 : Precise value (green). The river bed altitude is found by using another river bed altitude

from another cross section of the river in a really close area, i.e. not more than 20 meters around the centre of the bridge.
3 : Slightly imprecise value (yellow). The river bed altitude is found by using another river bed altitude from another cross section of the river in a close area, i.e. not more than 50 meters around the centre of the bridge in a curving river or 100 meters around the centre of the bridge in a straight river.
4 : Imprecise value (orange). The river bed altitude was roughly estimated using data from other areas.

Upstream river shape

1 : Exact information (blue). The criteria limit to determine the upstream river shape was well lower or higher the borderline leading to no doubt of the information.
2 : Doubtful information (orange). The criteria limit to determine the upstream river shape was really close from the borderline leading to an uncertainty about the information encoded.

3.2 Structural part

Opening shape, Abutments, Nb of piles, Piles shape, Handrail material, Structure damage

1 : Exact information (blue). A plan, a photo or a visit on site guarantees the exactness of the encoding.
2 : Doubtful information (orange). No plan, photo or visit on site was used or made leading to a doubtful information.

Width, Length, Thickness, Piles width, Piles protrusion, Handrail height

1 : Exact value (blue). The value is coming from a plan or from a direct on site measure.
2 : Precise value (green). The value is coming from a website or a software able to measure distances on pictures precisely (WalOnMap, ImageJ with an appropriate angle and elements of comparisons of exact measurement) or a direct measurement on site that was precise but not 100
3 : Slightly imprecise value (yellow). The value is coming from a software able to measure distances on pictures precisely (WalOnMap, ImageJ with an appropriate angle and elements of comparisons of precise measurement).
4 : Imprecise value (orange). The value is estimated by looking at photos for which the angle of view makes the use of a software imprecise and no on site measurement was possible.

Slope

1 : Exact value (blue). The value comes from a plan or is a calculation made using exact values on a plan.
2 : Precise value (green). The value is calculated using a software able to calculate a slope precisely on a structure knowing its coordinates or by doing a calculation using precise values of altitude on the bridge (see later altitude in the bridge fiability).
3 : Slightly imprecise value (yellow). The value is calculated using exact data of the river banks altitude where the structure is supposed to be located or by looking at a clear photo of the structure when the slope looks to be close to 0 °.
4 : Imprecise value (orange). The value is estimated using imprecise data of the river banks altitude or by looking at a picture of the structure.

Angle

1 : Exact value (blue). The value comes from a plan.
2 : Precise value (green). The axis of the river flow and the axis of the structure are easy to estimate, leading to a precise meaurement of the angle.
3 : Slightly imprecise value (yellow). The axis of the structure is difficult to estimate but the axis of the river flow is easy to evaluate.
4 : Imprecise value (orange). The axis of the river flow is difficult to estimate because the rivers banks are not parallel or the river is curving leading to an imprecise value of the angle.

Altitude on the bridge

1 : Exact value (blue). The altitude on the bridge is directly given on a plan.
2 : Precise value (green). The altitude on the bridge is found by using a software estimating precisely but with a possible margin of error the altitude on the bridge.
3 : Slightly imprecise value (yellow). The altitude on the bridge is calculated by using the exact value of the river bank altitudes at the exact location of the bridge
4 : Imprecise value (orange). The altitude on the bridge is calculated using the river bank altitudes from a cross section of the river that is not located exactly at the real bridge location or by using inexact values of the river bank altitudes.

Form open section

1 : Exact information (blue). A plan or bathymetry measures show the river bed altitude along the whole cross section, leading to an undoubtful information.
2 : Very probably correct information (green). An on site visit or photos when water level was low was used to determine the form open section.
3 : Probably correct information (yellow). A plan or bathymetry measures of a cross

section of the river that is less than 20 meters around the real cross section or on site photo when water level was quite low was used to determine the form open section.
4 : Doubtful information (orange). None of the possibles ways to estimate the form open section listed above was possible to use leading to a doubtful information encoded.

Distance between piles

1 : Exact value (blue). The value comes from a plan or from a direct measurement on site.
2 : Precise value (green). The value is calculated using a software able to measure a distance precisely via a well angled photo by knowing exactly the dimensions of other comparative elements or the value is coming from a direct on site measurement that wasn't 100% exact or the value is calculated knowing precisely the piles width and the length of the bridge and the structure is symmetric.
3 : Slightly imprecise value (yellow). The value is calculated using a software able to measure a distance precisely via a well angled photo by knowing precisely but not exactly other comparative elements or the value is estimated based on an on site visit that couldn't allow a precise measurement or the value is calculated using the piles width and the length of the bridge but one of those measurement is slightly imprecise while the structure is symmetric.
4 : Imprecise value (orange). The value comes from a visual interpretation of a photo that doesn't have an appropriate angle of view or the value is calculated knowing imprecisely the piles width and the length of the bridge and the structure is symmetric.

Handrail porosity

1 : Exact information (no color). The handrail is easily recognized in one of the examples proposed to evaluate the porosity leading to an exact information.
2 : Doubtful information (orange). The handrail is difficult to compare to the given examples or no picture of the handrail before the event was found.

3.3 Flood event at the structure part

Max water level

1 : Precise value (green). The altitude of the maximum water level was directly measured on site on a mark on a house for which its altitude is precisely known and which is located in a circle of 50 meters around the centre of the bridge.
2 : Slightly imprecise value (yellow). The altitude of the maximum water level was not directly measured on site but estimated on a mark on a house for which its altitude is precisely known and which is located in a circle of 50 meters around the center of the bridge or the altitude of the maximum water level was directly measured on site on a mark on a house for

which its altitude is precisely known and which is located in a circle of 100 meters around the center of the bridge.
3 : Imprecise value (orange). The altitude of the maximum water level was directly measured on site on a mark on a house for which its altitude is imprecisely known and which is located in a circle of 50 meters around the center of the bridge or the altitude of the maximum water level was directly measured on site on a mark on a house for which its altitude is precisely known and which is located in a circle of more than 100 but less than 200 meters around the center of the bridge or The altitude of the maximum water level was not directly measured on site but estimated on a mark on a house for which its altitude is precisely known and which is located in a circle of 100 meters around the center of the bridge.
4 : Very imprecise value (red). Any measurement less presice than what is decribed above or general data about a whole city is used.

Type of flow

1 : Exact information (blue). The water level compared to the altitude of the bridge and its thickness makes it certain to evaluate the type of flow.
2 : Doubtful information (orange). The imprecision of the altitude of the bridge, the thickness and the water level is so important that the type of flow becomes doubtful.

Discharge, Flow width

1 : Precise value (green). The value was foud using trustful data.
2 : Imprecise value (orange). The source of data is not trustful.

Max water depth

1 : Precise value (green). If both max water level and bridge surface altitude were of precision 1.
2 : Slightly imprecise value (yellow). If the lowest precision of max water level and bridge surface altitude was 2.
3 : Rather imprecise value (orange). If the lowest precision of max water level and bridge surface altitude was 3.
4 : Imprecise value (red). If the lowest precision of max water level and bridge surface altitude was 4.

3.4 Deposit and Main Debris part

Length, Width, Height

1 : Precise value (green). The value is calculated using a software able to measure a distance precisely via a well angled photo by knowing exactly the dimensions of other comparative elements.
2 : Slightly imprecise value (yellow). The value is calculated using a software able to measure a distance precisely via a well angled photo by knowing precisely but not exactly other comparative elements.
3 : Imprecise value (orange). The value comes from a visual interpretation of a photo that doesn't have an appropriate angle of view.
4 : Very imprecise value (red). The value comes from a visual interpretation of a photo that doesn't have an appropriate angle of view to the point that not 100% of the debris are shown on the photo.

Volume

1 : Precise value (green). The value is calculated using a software able to create a surface representing the debris precisely via a well angled photo by knowing exactly the dimensions of other comparative elements and by using an average height that would be of criteria 1 of precision.
2 : Slightly imprecise value (yellow). The value is calculated using a software able to create a surface representing the debris precisely via a well angled photo by knowing exactly the dimensions of other comparative elements and by using an average height that would be of criteria 2 of precision.
3 : Imprecise value (orange). The value comes from a visual interpretation of a photo that doesn't have an appropriate angle of view or by using an average height that would be of criteria 3 of precision.
4 : Very imprecise value (red). The value comes from a visual interpretation of a photo that doesn't have an appropriate angle of view to the point that not 100% of the debris are shown on the photo.
Location at structure
1 : Exact information (no colour). The photos of the accumulation of debris makes the location of the debris at the structure undoubtful.
2 : Doubtful information (orange). The photos are not showing properly the disposition of the debris at the structure.

Volume percentages and type of debris

1 : Precise information (green). The photos are clear and make it easy to determine the volume percentages and the different types of debris.
2 : Slightly imprecise information (yellow). A little part of the carpet volume is not visible on the pictures because it is underneath the surface debris and there is no guarantee that it is the same type than at the surface of the carpet leading to a difficulty to estimate the

percentages and nature of different debris.

3 : Imprecise information (orange). An important part of the carpet volume is not directly visible on the pictures because it is underneath the surface debris and there is no guarantee that it is the same type than at the surface of the carpet leading to a difficulty to estimate the percentages and nature of different debris.

4 : Very imprecise information (red). The pictures are not showing 100% of the debris meaning that the percentages of volumes estimation is probably wrong.

Chapter 3

Data analysis

This chapter presents the different analyses realised using the data coming from the database. It summarises the general data in order to have a global view of the characteristics of the bridges studied. It showcases the relations between sets of two parameters, trying to determine the influence of a parameter on another. Deeper analyses are made about the variables seeming to be a cause of cloggings.

The first section consists in graphs highlighting the main properties of the bridges studied. It indicates the value of each parameters defined in section 1. Distinctions are made between bridges and railway bridges as well as structures that caused clogging or not. This section concludes on the main differences existing between the structures studied and what parameters deserve further analysis. Based on those results, a second section analyses the relevant parameters which can be studied in combination with other ones to try to find correlation effects. This section establishes which are the dominant factors in the cause of cloggings. A third section proceeds in a deeper analysis of those dominant parameters. Those parameters are analysed together to determine which ones are the most important in the study of cloggings. A final section concludes about the influence of the different parameters on cloggings.

1 General results

This section provides the general information about the bridges studied. It specifies which structures were analysed in this project and which were not. The graphs are showing the differences between those structures based on their parameters values. Parameters are then classified depending on their interest for further analyses.

1.1 Bridges analysed

Not each structure located in the basin was studied in this project. As the analyses were directly dependent from the information obtained regarding the clogging of the bridges, it was impossible to gather enough data for every bridge. Figure 3.1 showcases the bridges studied in the project based on their type of structure (i.e. bridge or railway bridge) and based on their clogging information (i.e. no clogging, no information or yes clogging).

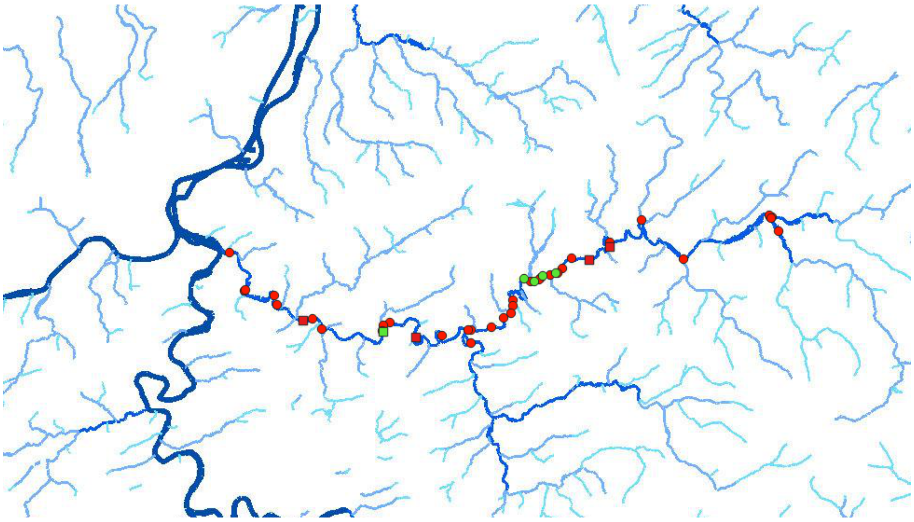

Figure 3.1: Location of bridges based on their type of structure and clogging information

Out of the 118 bridges from the Vesdre, Helle and Hoëgne rivers, 74 could not be associated with certainty to a presence of clogging or not. It may seem a lot but it is actually easily understandable considering that many bridges are in rural areas where less inhabitants could possibly take a photo of the cloggings. Aerial photos, which are really useful to notice the amount of damage made to the bridges and the presence of clogging when there is one, could not be used to guarantee the absence of clogging as they were taken too many days after the events, allowing the evacuation of debris. Indeed, many aerial photos were not showing cloggings at bridges despite other photos of those bridges coming from inhabitants could clearly identify one.

The main analyses are focusing on the bridges for which we know for sure that a clogging was created during the flood events. There are 39 bridges in that category. 35 are along the Vesdre river, 2 along the Hoëgne river. Even if it was not supposed to be studied during this project, 2 other bridges along the Helle river are analysed as photos of important cloggings for them were found. The 2 bridges from the Hoëgne river are a particular case as they are both next to each other at slightly different altitudes, one of them being a railway bridge. As the photos of the clogging show that the debris went over the first bridge and blocked by the second one, the analysis will be made only using the data of the most downstream bridge.

As for the bridges without clogging, we are only confident that 5 of them didn't cause cloggings during the floodings, all along the Vesdre river. To assume that those bridges didn't cause any cloggings, a few hypotheses were made. Those are the following :

- No photo shows the presence of clogging.
- The photos of bridges were taken not more than 2 days after the event, i.e. photos taken on 18/07/2021 and later are not a sufficient proof of no clogging. This hypothesis reduces

the probability that the clogging was already evacuated (naturally or humanly) when the photo was taken.

- The photos of bridges without clogging were taken by a specialist during a visit where other bridges with clogging were identified. Photos from inhabitants who were not focused on the debris could make us wrongly believe that there were no debris because the photos don't show them, not because there aren't, assuming an angle of photo not showing clearly the upstream part of the bridge. If a specialist during the same trip took multiple photos of clogging but also took photos of bridges without clogging, we assume that there were no clogging there.

The remaining bridges with no information were not considered in the analyses with the exception of damaged bridges where a clear damage was identified, without knowing if debris are responsible for that. Those bridges will be discussed at the same time that the clogging bridges in order to have visual comparisons with the graphs.

1.2 General analyses

The general information is presented using two different types of graphs and is commented afterwards.

The first type is a stacked bar chart and is used when the database only allows some possible answers. The abscissa axis regroups the different choices of information. The ordinate axis shows the amount of bridges present on the specific bar. The advantage of this category is that the fiability of the encoding was of exact precision for nearly each parameter, with the exception of few data from form open section which still were never considered as imprecise. The assumption is then made that those parameters are studied as if they don't require to take into account their fiability in the making of the graphs. This allows an easy and viewer friendly use of colors for those graphs. Colors will be then given based on the type of structure and the clogging information, using four different colors to describe those possibilities.

The second type of graph is also a bar chart but is used showing the value of each parameter. The ordinate axis assigns the value of each parameter while the abscissa axis represents every bridge and are simply ordered from 1 to 43 following the database order. The database starts with the clogged bridges from the river Vesdre from upstream to downstream, followed by the single bridge analysed among the Hoëgne and the two bridges from the Helle. The last 5 bridges are the ones without clogging. This order is followed in the graph abscissa axis in order not to have a color assigned for the nature of clogging. The color schemes can then be entirely used to follow the fiability assessment. This makes the regroupment of the railway bridges unclear to use. The solution used is to add a particular white point having a squared shape to each bar representing a railway bridge while the other bars are by default bridges. When other information has to be made for a better understanding, points of red colors appear in front on the corresponding bar with the adequate legend.

In order not to complicate the understanding of the graphs and to focus on the color schemes of the fiability, bridges without debris are as mentionned analysed in the same graphs than bridges with clogging. The distinction between those two types of bridges is made using a vertical dotted line at the separation of the clogged and without clogging bridges in the abscissa axis. The mention "Clogging" means than at the left ot that line, bridges are clogged while the mention "No clogging" means that at the right of that line, bridges were not clogged during the floods.

1.2.1 River bed parameters

Analyses of upstream river shape and form open section are shown in figure 3.2 and 3.3. We can notice that we have a lot of different scenarios of upstream river shape. The few bridges without clogging appear to have had all of the upstream shape possibilities even if we had a majority of curved left. Conclusions about the upstream river shape on bridges without clogging can't be made based on the data. However, the disparity of results obtained with the clogged bridges reinforces the interest to analyse this parameter further in combination with location of debris at structure. On the other hand, the form river section is less interesting. Most of the bridges are considered unregular which is quite expected as the river bed usually isn't constant. The parameter definition is lacking a bit of precision as it doesn't indicate height differences between unregularities nor the position of those, meaning that it is difficult to interpret any correlation between the debris accumulated and the unregularities. The experience gotten from encoding multiple bridges while looking at different photos of clogging leads to believe that this parameter is probably too situational to be analysed based on a database list. Furthermore, some of the encoded parameters were not precise due to lack of information about the river bed shape. For those reasons, no further analysis of this parameter will be made.

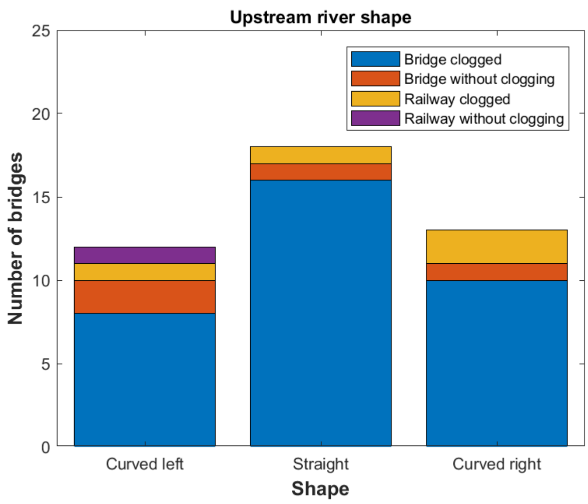

Figure 3.2: Upstream river shape

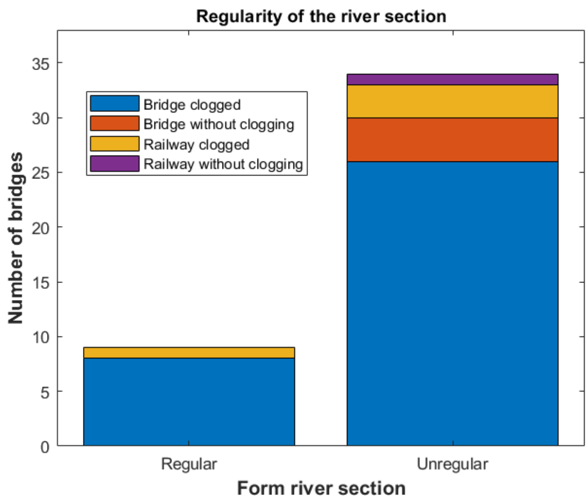

Figure 3.3: Form river section

1.2.2 Bridge parameters - global structure

Figure 3.4 is showing the distribution of the opening shape of the bridges. We observe a small majority (25 out of 43) of rectangular bridges compared to the arched bridges. We notice that every railway bridges have an arched opening shape, as expected and that not clogged bridges don't have a specific opening shape in common. Considering the distribution allows to compare a sufficient amount of bridges of both types of opening shape, this parameter will be studied further with total and carpet volume parameters. It is also considered not to take into account the bridges which their deck weren't reached by the water as the opening shape wouldn't have any consequence on the clogging. As for the abutments, the distribution showed in figure 3.5 presents a majority of bridges without abutments. The influence of the abutments seems low considering most of the bridges without clogging had ones. Furthermore, experience during the encoding of data didn't show any link between the abutments and the location of debosit. For those reasons, this parameter won't be studied further.

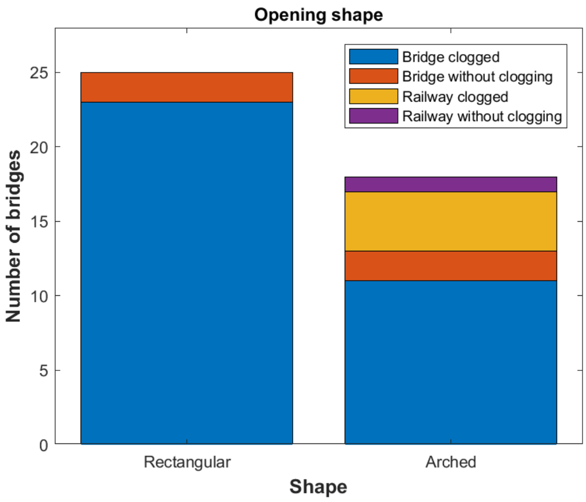

Figure 3.4: Opening shape of the structure

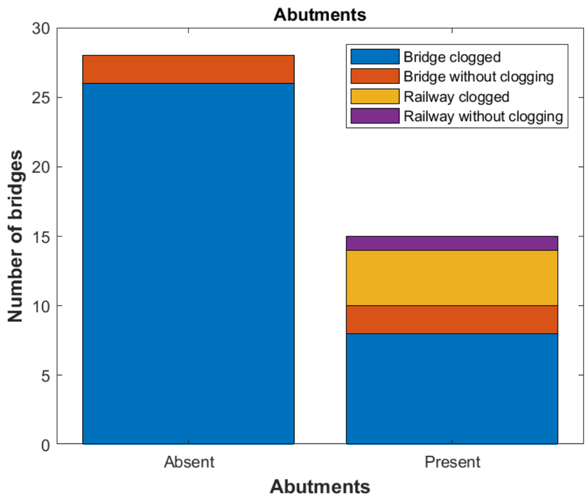

Figure 3.5: Abutments

In figures 3.6 and 3.7, we can observe the distribution of width and length of the bridges. We can notice an important disparity of values of width, varying from 1.5 meters to 22 meters. Railway bridges seem to have a more constant value as they simply depends on the amount of rail transport direction. Bridges without clogging don't share similar widths between each other, so no link between absence of clogging and width can be made based on the few data available. The lengths of the bridges are a bit more regular and also a bit longer in the case of railway bridges. The length of the bridge has an important role for the studying of this projet as it can be used to normalize the total volume and carpet volume of debris.

Figure 3.8 represents the angle made by the bridges with the river. We can notice a high variability of the values, even when taken as absolute values. The railway bridges tend to form more regularly an angle with the river. Not clogged bridges don't have angles above |12°| but so is the case of many clogged bridges that had similar angles. This parameter will be studied along

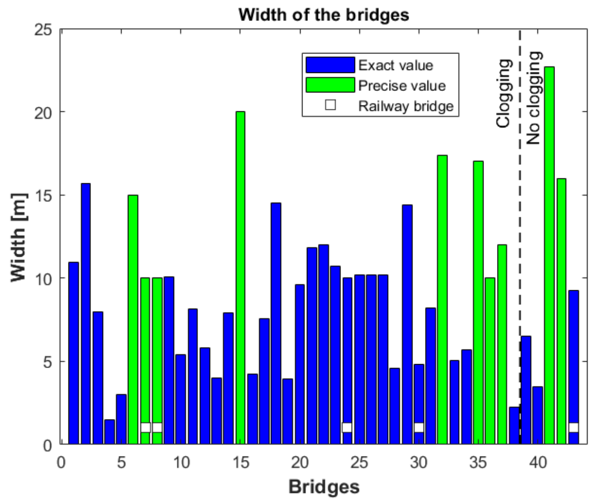

Figure 3.6: Width of structure

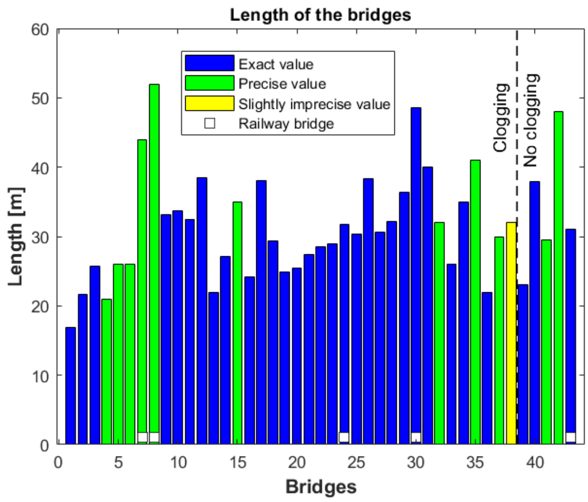

Figure 3.7: Length of structure

total and carpet volumes as well as location at structure with some precautionary regarding the amount of imprecise values. Figure 3.9 showcases the slope of the structures. We notice an important percentage of bridges with a slope close to 0% and below |1%|. However, an interesting amount of bridges have quite extreme slopes meaning that they could be studied in the next section along the total and carpet volume as well as location at structure considering a side of the structure is lower elevated than the other, reducing the height above river bed.

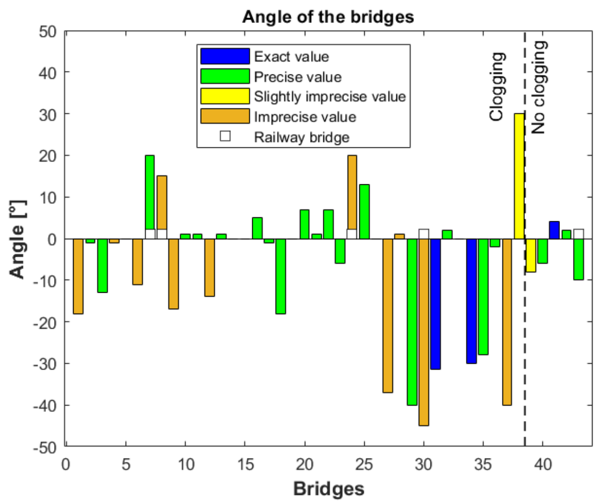

Figure 3.8: Angle of the structure

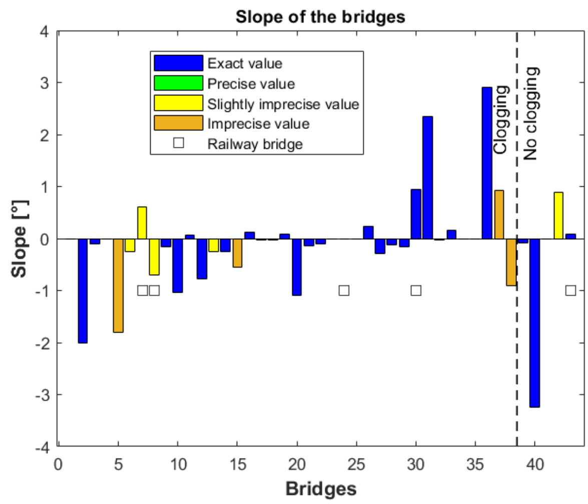

Figure 3.9: Slope of the structure

Figure 3.10 gives the distribution of thickness of the bridges studied. We can notice a quite important variability in the results, having sometimes a very low thickness of 0.5m or below, and other bridges with thickness of 1.5m or more. Bridges without clogging had important thickness as there is only one of those bridges having a thickness under 1m. It isn't sufficient to conclude that thickness isn't an important factor in clogging, though. The bridges with the highest thickness often are railway bridges and are also the main ones having an imprecise data. It is because in was not possible to find plans of all of them and that on site visits are obviously impossible to realise for those bridges for safety reasons. The disparity makes the analysis of the thickness of the bridges with total and carpet volume interesting. However, it is important to note that to be able to analyse the thickness of bridges correctly, those bridges had to have made contact with water and potentially debris during the floods to have pertinent conclusions about the influence of thickness. This means to take into account another parameter such as type of flow in the analysis.

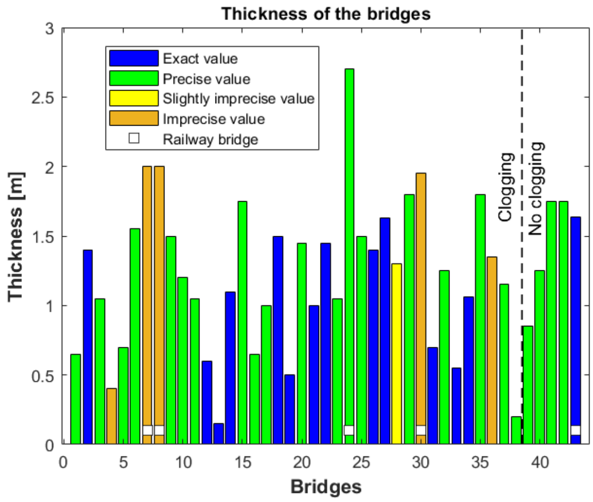

Figure 3.10: Thickness of the structure

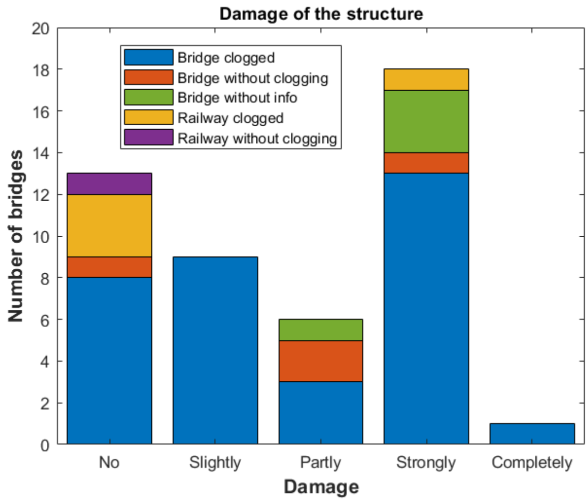

Figure 3.11: Damage of the structure

As for the damage of the structure, 3.11 indicates that a lot of bridges suffered different kind of damage. Some were not damaged at all, especially railway bridges but most of them were strongly damaged. It would be interesting to compare this parameter with the total volume, the type of debris as well as discharge and maximal water depth. The use of curvilinear abscissa could help showcase the sequence of the structure damaged.

1.2.3 Bridge parameters - piles and handrail

Figure 3.12 gives us the amount of piles for the bridges studied. We can see a huge diversity in the results with at least 9 bridges having either 0, 1 or 2 piles. We also notice that 3 out of the 5 bridges without cloggings didn't have any pile and only one time more than 1 for the railway bridge. Based on these informations, further analysis will be made considering the amount of piles with the total and carpet volume as well as location at structure. Figure 3.13 showcases that most of the bridges had a round nosed pile followed by some sharp nosed bridges. The amount of circular and square nosed piles is low. This parameter is probably less important than the amount of piles but will still be checked in the next section in comparison with total and carpet volume. Specific pile carpet can also be analysed with pile shape as the debris are only located on the pile meaning that the shape of the pile has an importance.

Distance between piles is an important parameter susceptible to cause blocking when debris of high width are blocked by a narrow distance between piles. Figure 3.14 shows huge differences between the values as bridges without pile are taken into account, meaning that the distance

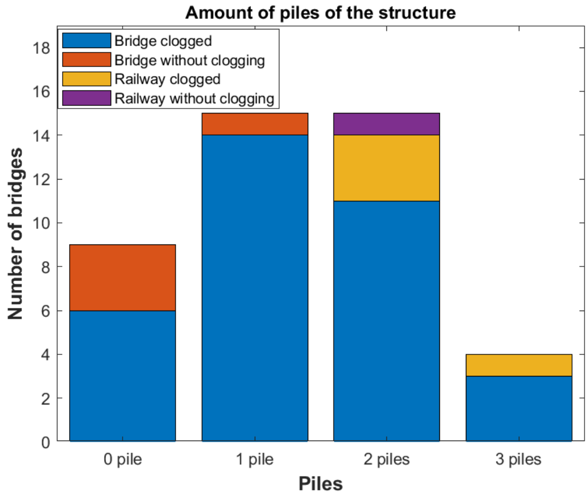

Figure 3.12: Amount of piles of the structure

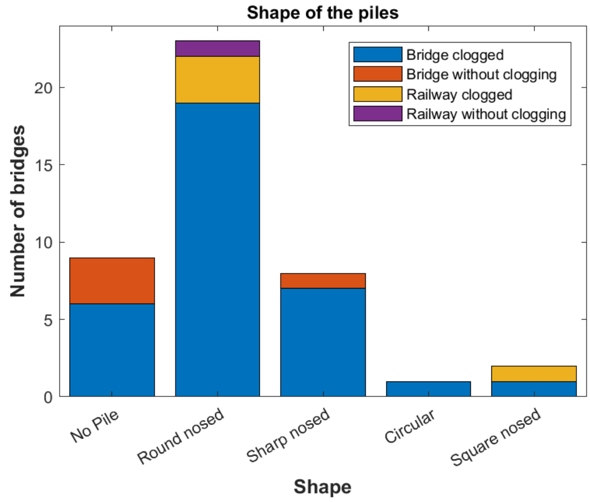

Figure 3.13: Shape of the piles

is the one between the banks or abutments, usually equal to the length of the bridge. As this parameter is often correlated with the amount of piles, it could be interesting to try to find which one has the most influence on debris accumulation if any of them has. Regarding piles again, pile width is also a factor which plays a role with distance between piles and pile shape. This parameter is essential to analyse with pile carpet volume as those are stucked on the pile. We can see in figure 3.15 that most of the bridges tend to have a pile width of around 1 meter and that railway bridges have wider piles. Despite this lack of diversity, pile width will still be analysed as non neglectable amounts of bridges have a pile wider than 1 meter.

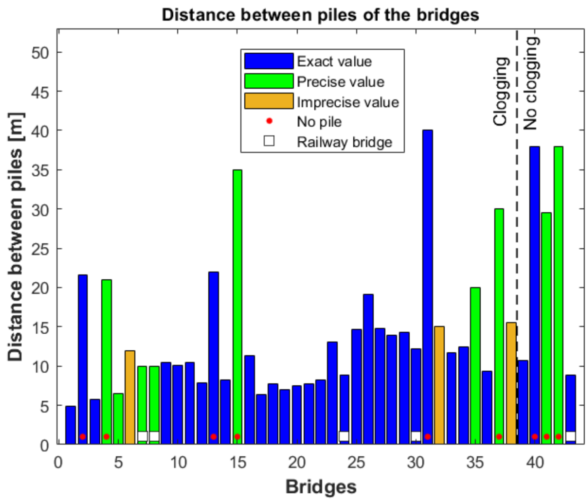

Figure 3.14: Distance between piles

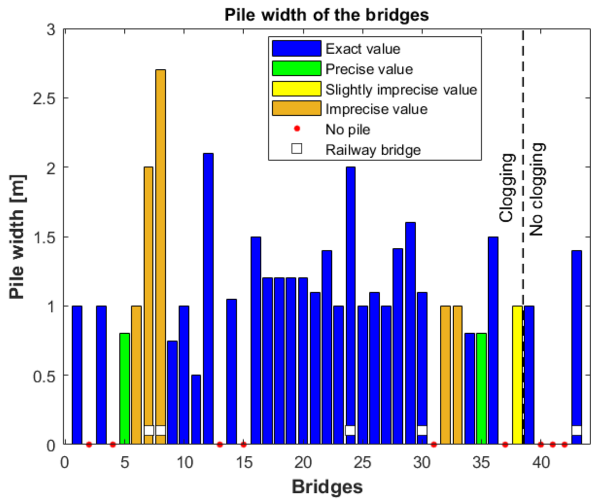

Figure 3.15: Pile width

Handrail protrusion is the last parameter focused on the piles. Railway bridges are not taken into account in that category due to their piles having usually a succession of different protrusions from the top of their deck to the bottom of the piles. Water height for those bridges were also often difficut to estimate as shows figure **??** leading to a difficulty to evaluate the correct protrusion to take into consideration. The analysis focuses then only on the bridges. We can observe that most of the bridges have a protrusion close to 0.5m but that it is often a visual

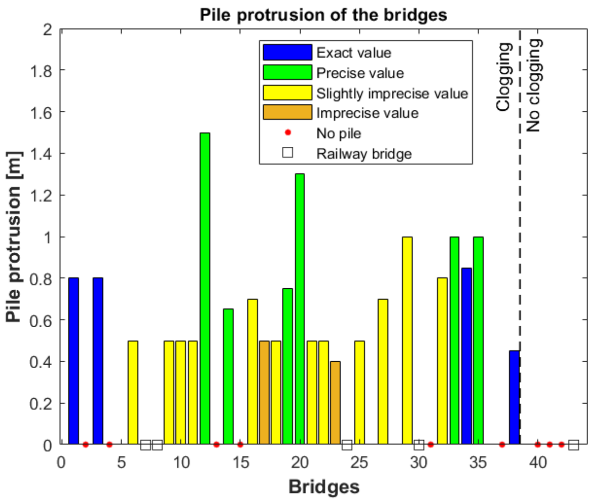

Figure 3.16: Pile protrusion

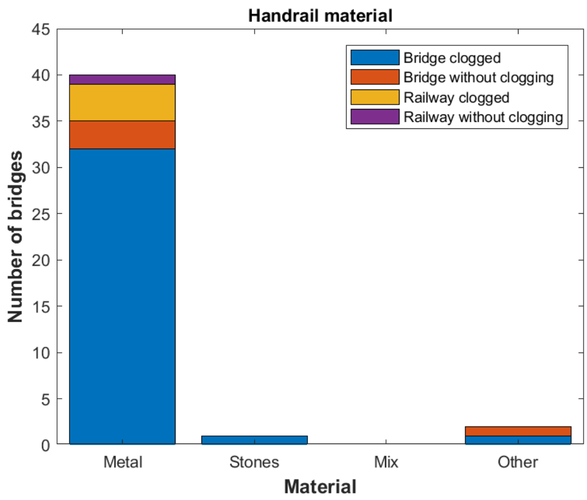

Figure 3.17: Handrail material

interpretation coming from a visit on site that couldn't allow a precise measurement or simply made by looking at photos with a bad angle. The values with a better degree of precision tend to be higher than the others. As some cases have extreme values, either on high distance or simply because there is no protrusion, the parameter can still be studied to see if it has an influence on the volume accumulated, especially on pile accumulations. Seeing no protrusion on the bridges without clogging is misleading because only one bridge really had a pile without protrusion.

Regarding handrails, figures 3.17, 3.18 and 3.19 clearly show that the handrails are most of the time designed in a similar way along the bridges studied in this project. Nearly all of them were metal handrails of around 1m with high porosity, making it nearly impossible to judge the influence of those parameters on the accumulation of debris. When the handrail was completely broken, even the visit on site couldn't help measure its size as it was already replaced by another one different, leading to no data exploitable or imprecise value based on previous photos. While some handrails can certainly increase the obstruction of debris, the fact that many were destroyed at least partly reduces even more the interest to study this parameter as it is impossible to really know when the handrail got broken and what effect it had on the debris accumulation. For all of those reasons, handrails won't be studied further in this project.

1.2.4 Flow parameters

Two connected parameters are expected to have a major influence on the accumulation of debris. Those are the maximal water depth and the type of flow. **Ruiz-Villanueva and al. 2014-2**. When the water height is sufficiently high, floating debris can reach the thickness of the deck or the handrail to get stucked in and cause the accumulation of other debris. If water height is below the thickness of the deck, the probability that a floating debris gets clogged by the deck is highly decreased and mainly depend on other parameters as number of piles, piles width or

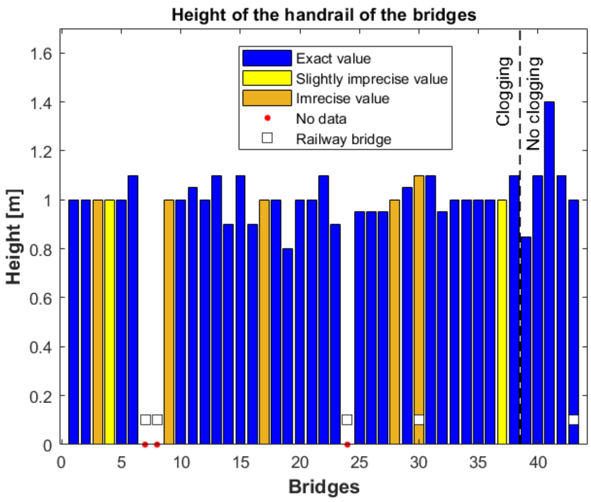

Figure 3.18: Handrail height

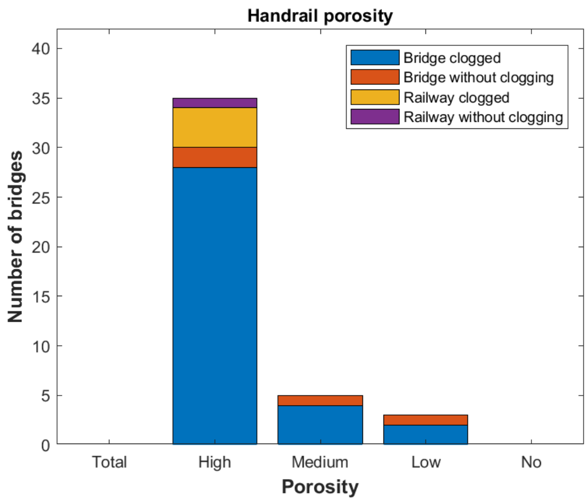

Figure 3.19: Handrail porosity

distance between piles. Figures 3.20 and 3.21 give us a good representation of those parameters.

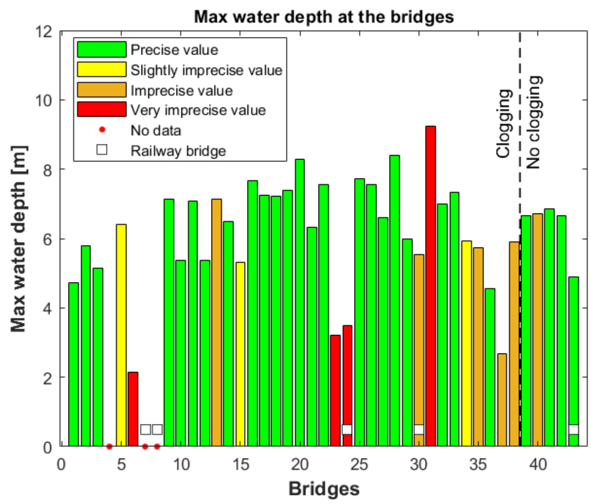

Figure 3.20: Maximal water height

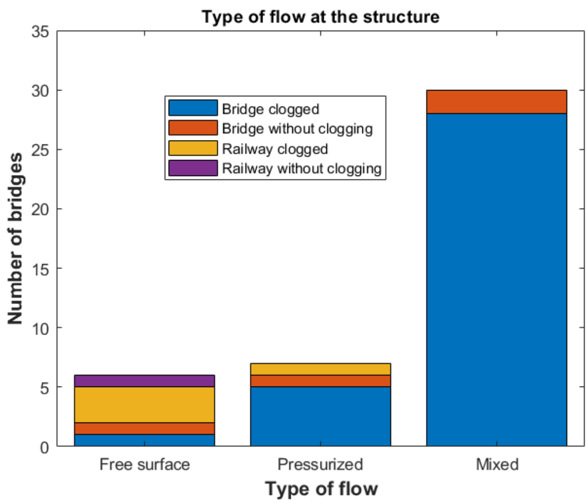

Figure 3.21: Type of flow

Maximum water depth reached in most cases at least 5 meters with multiple bridges having around 7 meters. The only bridges without at least 4 meters of water depth have an imprecise or very imprecise data. This situation happened a lot of times for bridges in rural areas and for railway bridges as their are located in places where houses were far from them, meaning that the possibility to use a mark of the water to know the water height was difficult and sometimes impossible due to the distance. The "no data" bridges were in a case where the water height was taken in a place usually more than 200 meters away from the bridge considered, falsing the results to the point that the type of flow associated was different than the trustul one that could be observed based on photos of clogging or damages. Those bridge along with the ones with very imprecise data won't be analysed further due to the probability of falsing the interpretations.

While figure 3.20 informs about the water depth, it doesn't indicate by itself at which level the water was elevated compared to the bridge as it is dependent from the river bed elevation and the bridge surface elevation. This is the role of the figure 3.21. It indicates the amount of bridges which were under (mixed), higher (free surface) or in between (pressurized) the maximal water elevation. The main result showed by the figure is that most of the bridges were in mixed conditions. The amount of clogged bridges seems to increase with higher water height compared to the bridge level. It also showcases that railway bridges were nearly all the time at free surface, meaning that the clogging was not due to the deck thickness. It reinforces the interest to treat differently the bridges depending on their type of flow conditions.

In order to try to analyse with more precision the influence of water height, new parameters are considered. The first is the height above the bridge surface, which is a direct measure obtained by the difference between max water elevation and bridge surface elevation which were both treated in this project. This parameter will only be used for bridges in mixed conditions. Precision of the data is the lowest degree of precision between the two parameters used to obtain the new one. Figure 3.22 gives an idea of the water height above bridge. The second parameter will be used for the bridges in pressurized or free surface conditions and is the height above river bed, representing the height between the bottom of the thickness of the bridge and the lowest elevated part of the river bed. This parameter will appear in the next analyses.

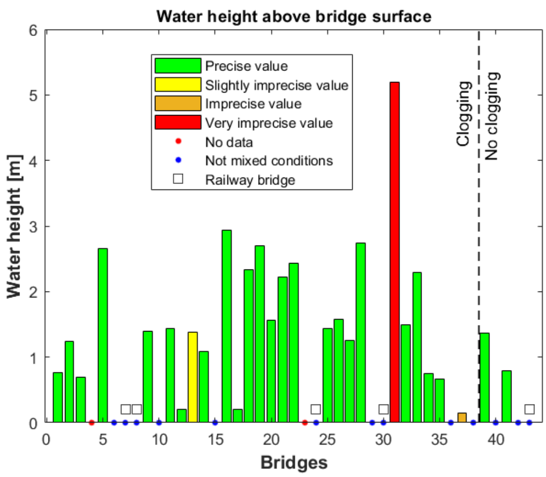

Figure 3.22: Water height above bridge surface

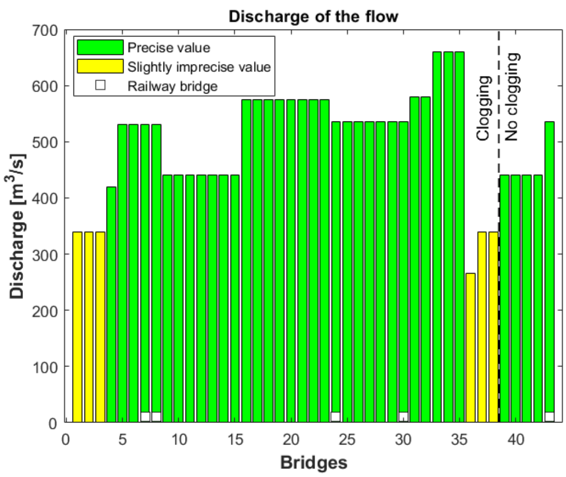

Figure 3.23: Discharge

Figure 3.22 shows that a lot of disparities are noticed in the water height values. It is then really interesting to compare it to the volume values. Bridges under free surface or pressurized flow are marked by a blue circle while bridges in mixed conditions but without real data about water elevation are marked by a red circle. A disproportionnate value of water height is considered very imprecise, this value won't be considered in the analyses with volume. Bridges without clogging tend to have lower water heights.

As for discharges, they are represented in figure 3.23. The values are considered mainly precise as they come from a specific report from the University of Liège but they are in reality quite difficult to use as they are not showing the real discharge going through the bridges but are using the overall flow width of the flow, which was not publicly specified. The data obtained for that last parameter is then completely approximative in this project, which is why no figure is made about it. Those 2 hydraulical parameters are then not used lated in this project, even though some allusions about them can still be made in the discussions.

1.2.5 Debris parameters

The first parameter analysed is the location of debris at the structure and is given in figure 3.24. This figure shows that a lot of the cloggings were spread along the whole width of the structure or on the piles. An important part of the debris were also in priority linked with one of the banks, while a few of them were located only on the center of the bridge. The rest of the cloggings are located on the handrails. This parameter will be analysed in correlation with total and carpet volume as well as the other parameters previously mentionned. Depending on the results, further analyses focused on a certain location could be made. On the other hand, figure 3.25 gives the information of the presence of a main trunk in the clogging. This parameter shows little interest as too many cloggings couldn't make it possible to know if there was a trunk causing it at first place or not. However, there is not a single case where it was certain that a clogging appeared without the presence of a main trunk.

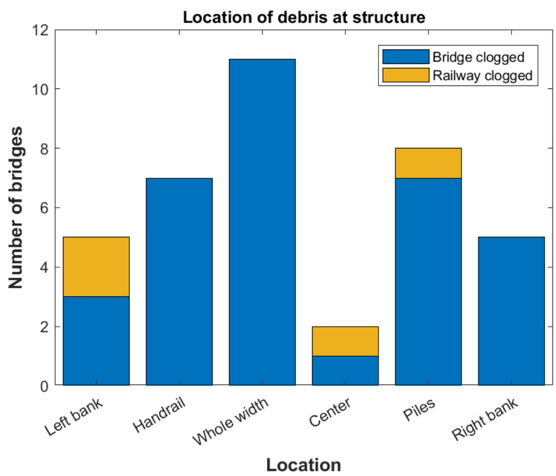

Figure 3.24: Location of debris at structure

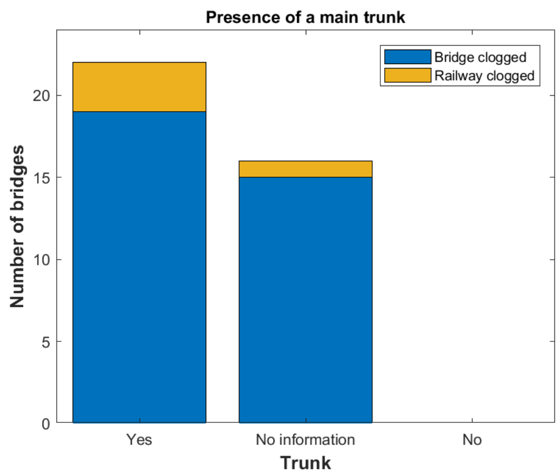

Figure 3.25: Presence of a main trunk or not

Let's now have a look at the most important parameter to analyse in the studying of clogging : the amount of volume of debris. Figure 3.26 gives an overview of the total volume of each clogged bridge, in $[m^3]$ units. It is observed that a majority of the bridges were clogged by debris representing between 30 and 100 m^3. However, a non neglictable amount of bridges were clogged by really high volumes that were above 200 m^3, and 4 of them were close to or higher than 500 m^3. Regarding carpet amount of debris, they seem to follow quite well the amount of total debris under most cases. It can be seen when the carpet volume is equal to the total amount, observed in the figure when the circle and the hexagram coincide each other. At other times, a difference can occur, meaning that a part of the total volume is outside the carpet. In term of percentages, when the total volume is high, the effect of the reduced carpet volume seems low as the total carpet volume remains high. However, up to 9 carpet volumes reached a value of 0 m^3. All of them appeared when the total volume was already quite low. It would be interesting to know the situations where it happened. 3.1 summarizes the different information.

The first reflection to analyse a bit deeper the amount of volume would be to think that it can be caused by the length of the bridge. Indeed, it seems logical that the longer the length of the bridge, the greater the amount of debris it can block. This is why the normalized total volume is also represented in figure 3.27. It shows the total amount of volume devided by the length of the bridge. The river width could'nt be considered to normalize the volumes as during the floodings, water goes outside its minor bed and doesn't have a precise nor constant value. The minor bed width is also sometimes under the length of the bridge, falsing the results of the real amount of volume blocked by surface [m^3/m].

While looking at the appearance of both graphs, there is a trend that most bridges at low volumes kept their position compared to the other bridges. For higher volumes, it seems that some differences in the positions occured as the gap between high and low normalized volumes seems to be reduced. It suggests that for bridges with high volume of debris, the length of the bridge can actually play a role in the total accumulation.

Regarding the fiability of the encoding, it is observed that there is a lot of diversity in it. Many volumes were calculated imprecisely or very imprecisely (a bit less than 50% are in that category). Some of the very imprecise volumes are on the extreme low or high amounts of normalized debris, while the others seem to fit in the norm of the graphs. Railway bridges seem to have a higher rate of imprecision calculated. it is because the plans of their dimensions were not always available nor accurate meaning that the volume calculated was also imprecise. During the encoding of the database, it was noticed that the fiability of the carpet was usually the same as the one of the total volume. This allowed to use a legend on the graph without specifying the fiability as it is assumed the same as the total volume.

Table 3.1 highlights that the standard deviation is really high for the total and carpet volumes of bridges. It is also suggested by the median being way below the mean value. The railway bridges tend to have lower volumes. The difference between carpet and total volume is low.

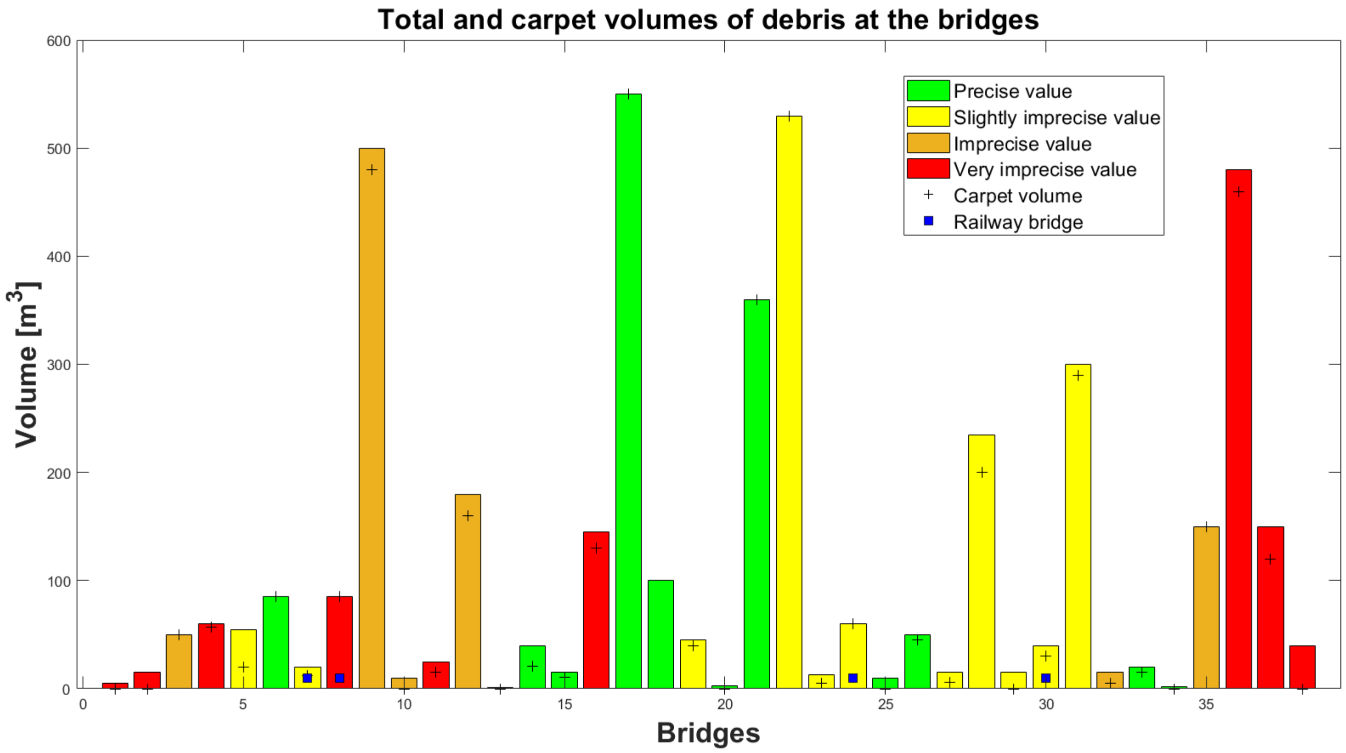

Figure 3.26: Total and carpet volumes of the bridges

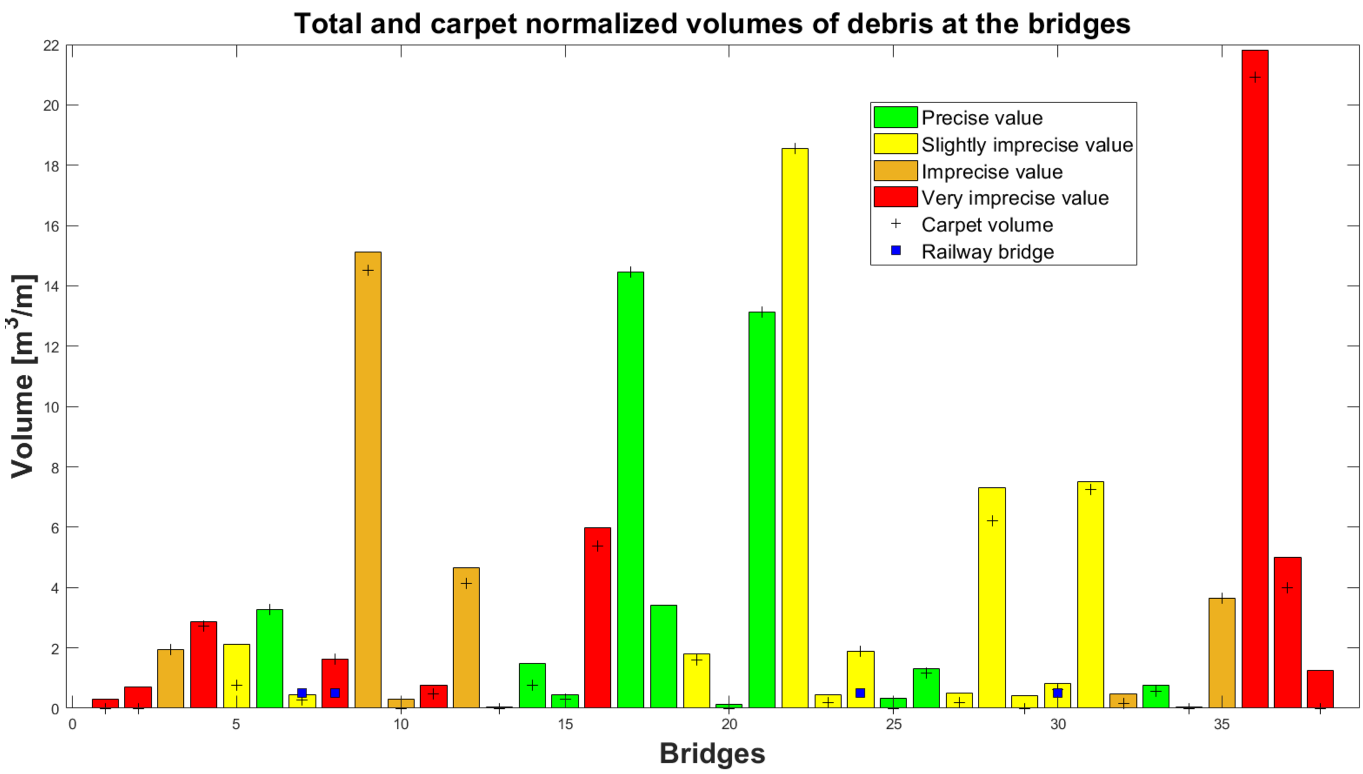

Figure 3.27: Total and carpet normalized volumes of the bridges

Parameter (unit)	Structure	Mean	Median	Standard deviation	Min value	Max value
Total Volume (m^3)	Bridge	127.04	47.5	168.99	1	550
	Railway bridge	51.25	50	27.80	20	85
	All	119.06	47.5	161.52	1	550
Normalized Total Volume (m^3/**m**)	Bridge	4.23	1.64	5.76	0.04	21.82
	Railway bridge	1.20	1.22	0.67	0.45	1.89
	All	3.91	1.55	5.52	0.04	21.82
Carpet Volume (m^3)	Bridge	113.66	20.5	170.14	0	550
	Railway bridge	46.75	45	32.28	12	85
	All	106.61	25.5	162.28	0	550
Normalized Carpet Volume (m^3/**m**)	Bridge	3.77	0.77	5.78	0	20.90
	Railway bridge	1.10	1.12	0.78	0.27	1.89
	All	3.49	0.77	5.52	0	20.90

Table 3.1

Figures 3.28, 3.29 and 3.30 show the total and carpet width, length and height of the cloggings. Those elements allow to showcase which structures had some peak accumulations of debris and which didn't. Every figures display an important variability of the results. The correlations between total length, width, height and total volume will be studied in the next section, as well as their carpet values. Observing the figures at first stance, it seems like the total length doesn't have an influence on total volume on the contrary of width. It seems logical considering that it is difficult to have a clogging width wider than the length of the bridge in some situations while the total length can be increased by residual debris on the top of the bridge. Regarding that aspect, carpet length, width and height seem to be more interesting to analyse. They are indeed way more closer to the mean real values of width, length and height causing the carpet volume.

1.2.6 Conclusion

This section allowed to realize that many parameters could be interesting to study further. The first graphs couldn't already conclude on some parameters being a source of clogging but showed an interest especially on the opening shape, the piles and water heights simply using that general data and information about the type of structure and the existence of clogging. A distinction between the railway bridges and other bridges was made based essentially on the type of flow, thickness, and width of the piles. Some parameters as age of structure or flow width couldn't be analysed due to lack of data. Other parameters like the handrails were judged ininteresting to analys due to their lack of diversity.

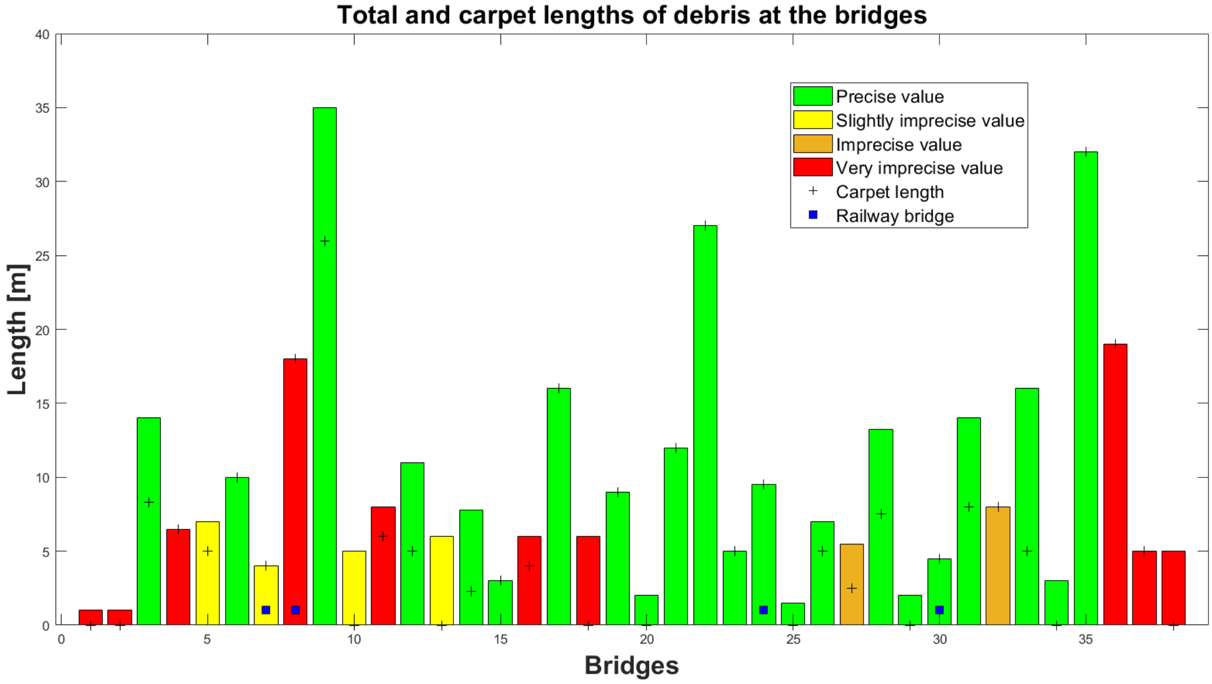

Figure 3.28: Total and carpet lengths of the bridges

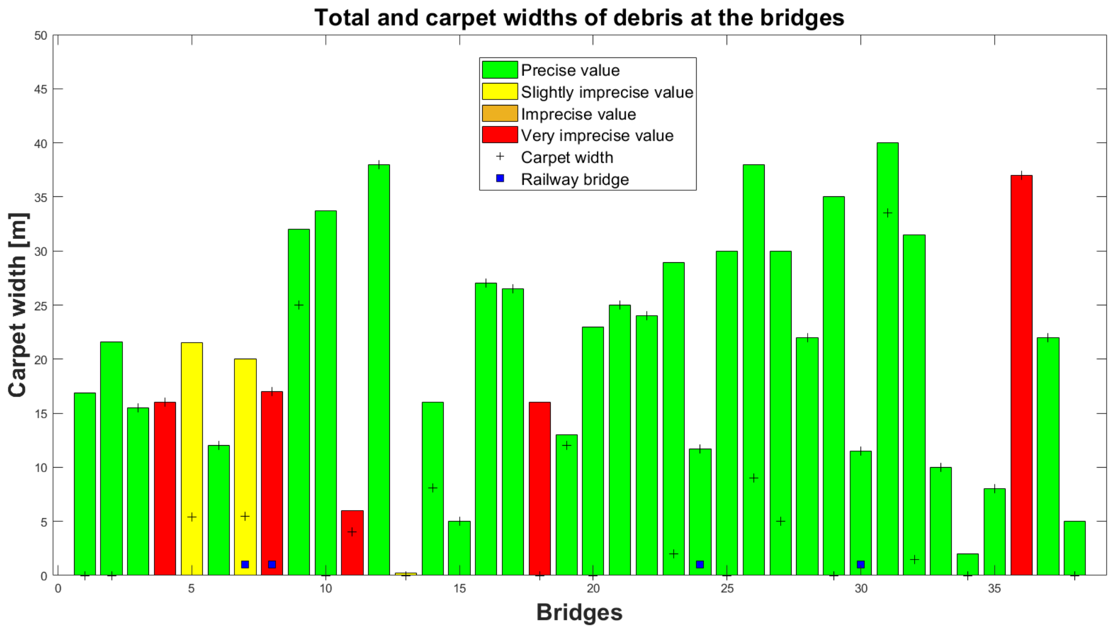

Figure 3.29: Total and carpet widths of the bridges

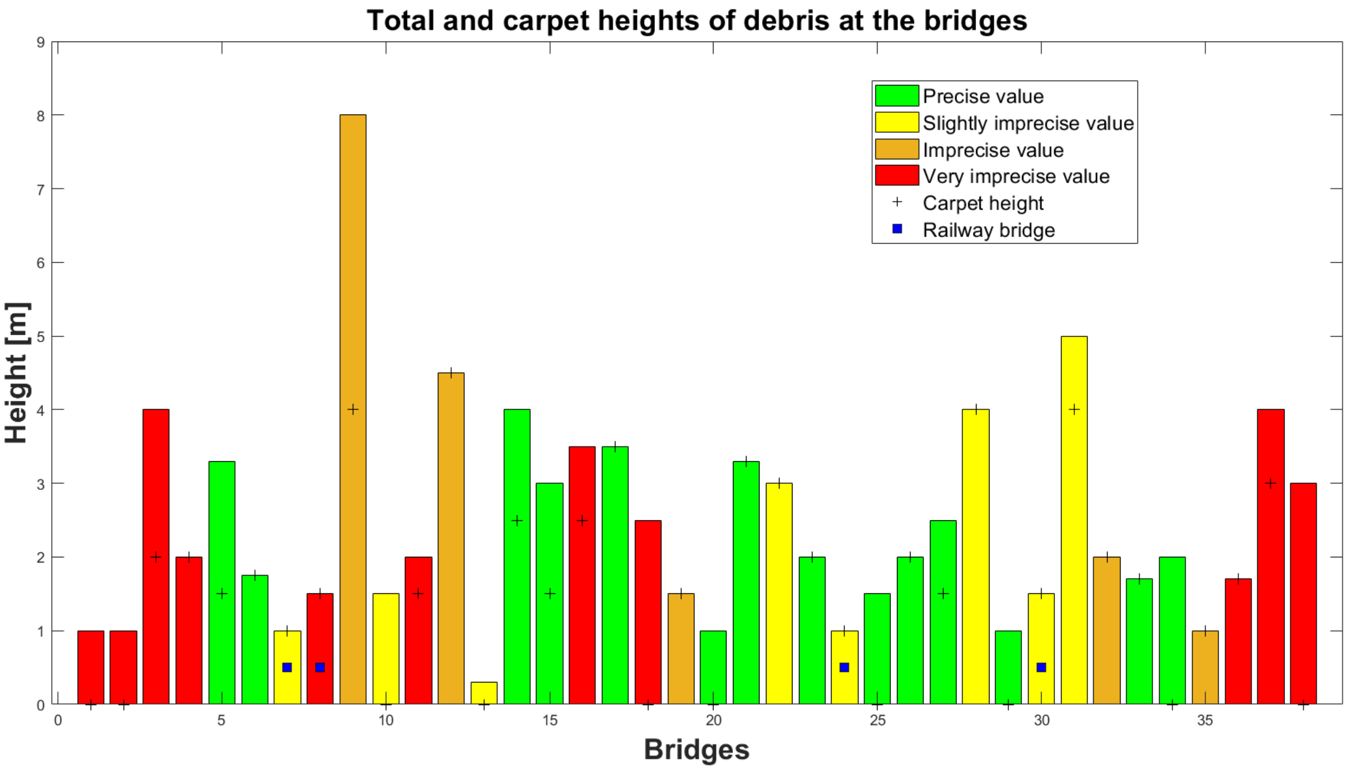

Figure 3.30: Total and carpet heights of the bridges

2 Two parameters analysis

In this section, the correlations between two parameters are studied. The interest is to determine whether or not a certain parameter has an influence on a second. This process will allow to determine what are the dominant factors in the forming of cloggings, without being able to conclude on the main causes of cloggings yet. This section will mainly focus on the amount of volume as it is the most important aspect of the cloggings. Volume will be compared to all of the other parameters that were judged relevant after the general analysis. The end of section will compare other parameters than volume to each other. A general conclusion will close this section.

2.1 Volume and other parameters

The following hypothesis is made regarding the analyses of the cloggings : each encoded value associated to a fiability of level 4 is not considered in the analysis. This allows to make sure that very imprecise clogging values are not considered as they could false the interpretations of the results. It may seem odd as figures 3.26 and 3.27 didn't showcase too many extreme very imprecise values that could look suspicious by being out of the norm. Indeed, with the exception of 3 bridges, most of the red coloured points of the figures were close to other values. This is not a sufficient proof to keep those values in the next analyses. Indeed, very imprecise data regarding volumes means that the debris were not possible to be observed in their entirety. The volume was then totally guessed based on the visual observations available. Some bridges were encoded with a 150 m^3 value by assuming the presence of a carpet along the whole width, even if it was not showed clearly. Other bridges had quite small amount of volumes because the photo was taken too far to assume anything, missing probably an important part the real clogging and under evaluating the real amount. As it is never possible to know if the encoded value is close to the reality or not, those very imprecise volumes are not considered.

Imprecise values related to structural part are also considered as degree 4 of precision. The imprecision may seem less critical but for structural elements, this is sufficient to cause trouble to the interpretation. A thickness could be poorly evaluated based on a photo with a bad angle of view (definition of criteria 4) and misvalued of 30 centimeters, which can change the result drastically. An angle of bad precision could be wrong of 10 degrees and completely channge the interpretation of the results as well. This is why degree 4 of precision for other elements than volume is also unconsidered in the next analyses.
As done in the previous section, the analyses will be made following two types of graphs.

- The first one is when the volume is compared to a parameter offering different kinds of answers. Those propositions will form the x axis. The volume values will be given on the y axis and showed by using a green circle. Those values will then stay on the same x value to show in which category they are part of. For those graphs, total volume will be compared with carpet volume in order to determine if a particular case increases the probability to have differences between carpets and non carpet volumes. The carpet volumes will be shown using blue points in hexagram form. They will not be on the same x value than their respective total volume but close enough to understand they are part of the same category. Next to those graphs will be given the same ones using normalized volume to have another source of interpretation.

- The second type of graph is when the volume is compared to a parameter which doesn't have restrictive values. In those cases, the total volume will be shown on the y axis using the respective other parameter in x axis. The volumes will be represented simply by circles. in that scenario, carpet volumes are not show as they would block the view of the user too much. The normalized volume graphs are shown as well for comparison.

2.1.1 Debris data

Location at structure It was seen previously that most of the cloggings appeared in very diversified locations at the struture. Figure 3.31 shows the volume and carpet volume reached by each clogging depending on the location. It can be seen that the biggest volumes were mainly reached when the whole width was targeted. It is an expected result as it means that debris didn't focus on a part of the bridge but on its entirety, increasing the blockage surface and then the volume. Every bridge that faced deposit on its whole width had at least 100 m^3 in its clogging and at least 3.5 m^3/m as shows figure 3.32. Only an exceptionnal bridge on the right bank reached similar levels of total or carpet volumes as the ones on the whole bridge, while on the left bank, a bridge also stands at more than 150 m^3. We can conclude that those 3 types of locations are accumulating larger amounts of volumes, with a net superiority of the whole width location.

On the other hand, location at handrails reached very low volumes. This is quite expected as the clogging appears only on the surface of the bridge and its handrails, which is the reason why a large amount of carpet piles was equal to 0 m^3. As for the piles, the amount of volume is also quite low even though non neglectable. Piles carpet have lower volumes since only the biggest pile is considered, which considerably reduce the value of volume when compared to total volume in the case of 2 piles clogged.

Width, length and height Figures 3.33, 3.35 and 3.37 indicate the influence of the length, width and height of the debris on the total volume. It can be observed that the total length seems to have a tendency to cause bigger accumulation of debris above an important value of length, i.e. 10 meters or so. For the lower volumes, the effect of the total length of the debris on the total volume isn't significant. The same observation can be viewed for total width and total height which start to have an impact on the volumes mainly after a critical value. In figures 3.34, 3.35 and 3.37, the same graphs about specific carpet dimensions are made. It is observed a slightly faster correlation as the carpet volumes don't take into account the very

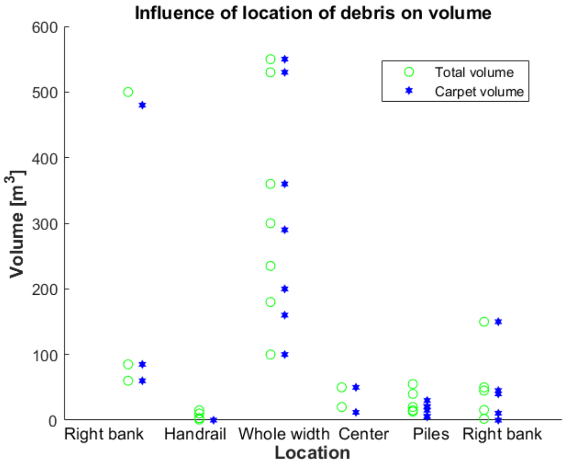

Figure 3.31: Location at structure and volume

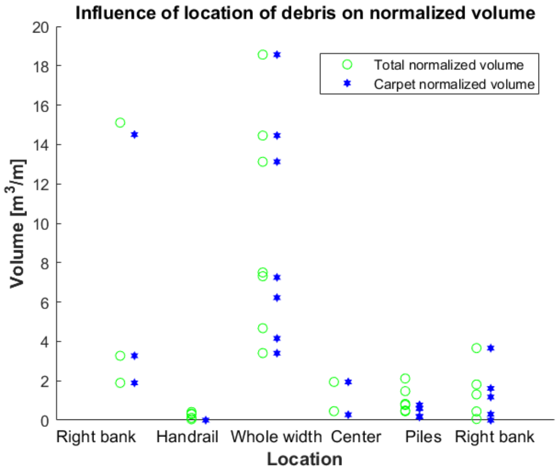

Figure 3.32: Location at structure and normalized volume

low volume cloggings that are not considered as carpet and which could, by accumulation of non consistent debris, false the total values.

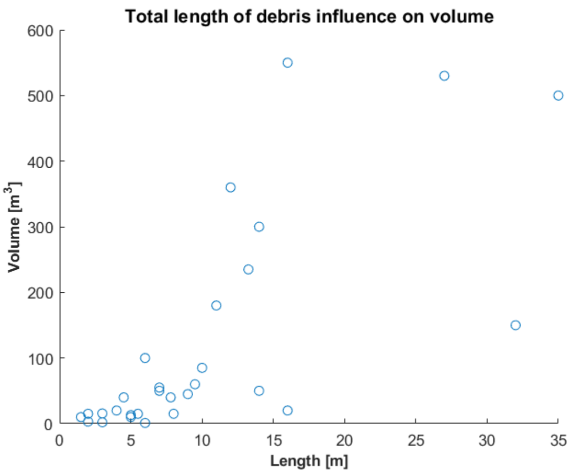

Figure 3.33: Length of debris and volume

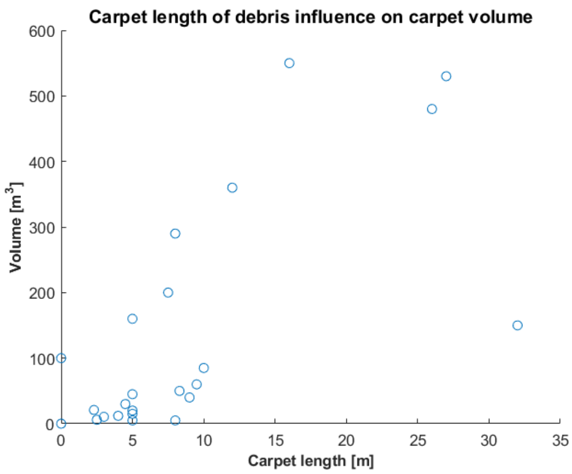

Figure 3.34: Carpet length and carpet volume

2.1.2 Main structural elements

Opening shape The influence of opening shape is shown in figures 3.39 and 3.40. Only mixed and pressurized conditions were analysed in the project as the free surface flows don't make contact with the deck on the bridge which is forming the opening shape. It can be observed that arched volumes tend to accumulate more volume than rectangular ones. Most of the arched bridges face lower than 100 m^3 as only 2 out of 7 reached a volume higher than that while for the rectangular ones, multiple bridges reached volume in the ranges between 100 and 550 m^3. The extreme volume is arched, though. Normalized volume seems to indicate that this volume is linked to the length of the bridge as it is not the bridge with the highest normalized volume.

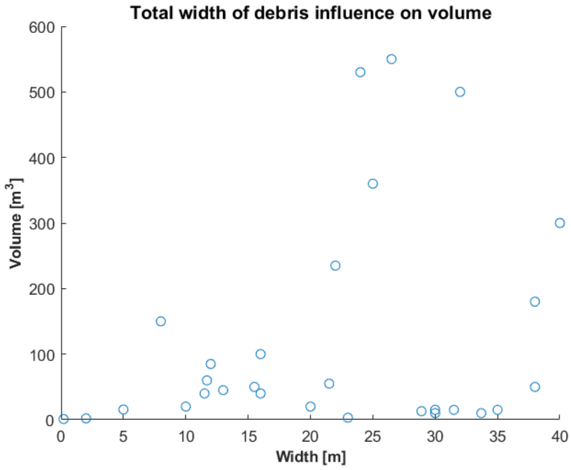

Figure 3.35: Width of debris and volume

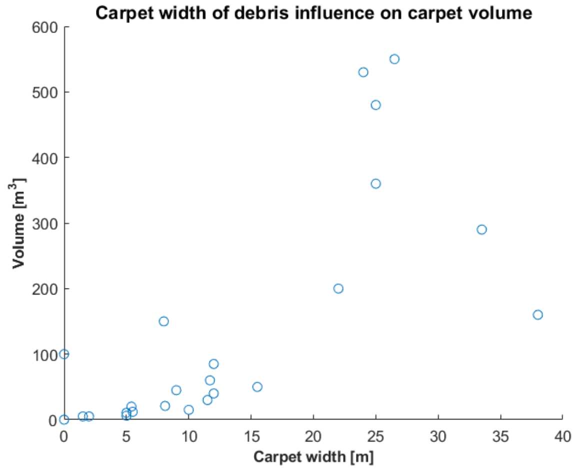

Figure 3.36: Carpet width and carpet volume

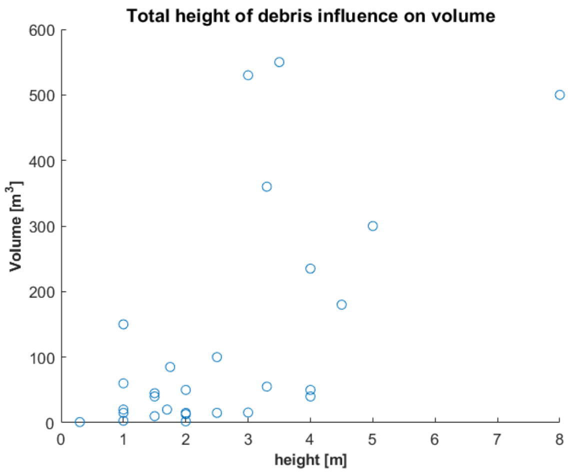

Figure 3.37: Height of debris and volume

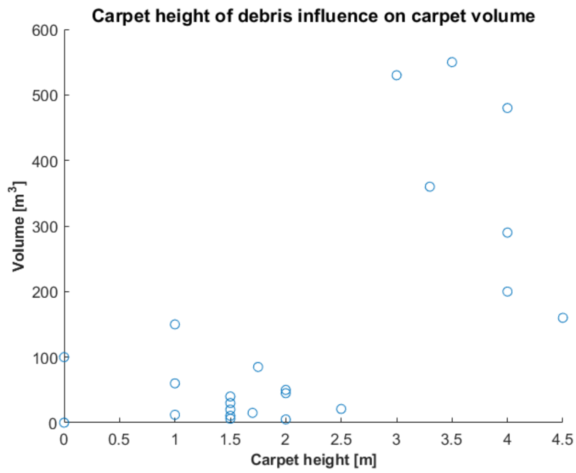

Figure 3.38: Height width and carpet volume

This indicates to consider the opening shapes in further analyses. However, concluding that rectangular openings are a direct factor of clogging is a bit early as other factors were not considered such as thickness of the bridges and water height above bridge.

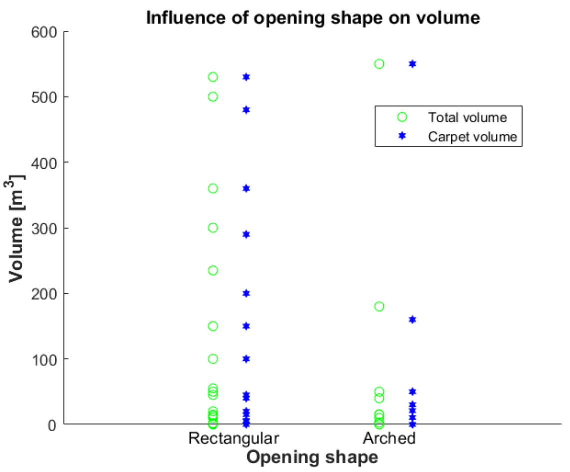

Figure 3.39: Opening shape and volume

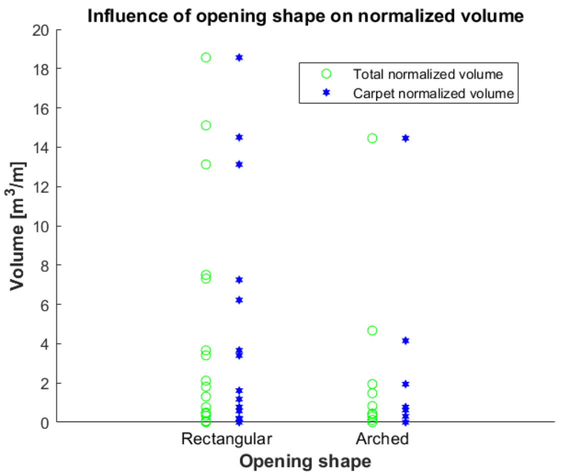

Figure 3.40: Opening shape and normalized volume

Slope The effect of slope on volume is analysed in figures 3.41 and 3.42. Original results don't seem to have any correlation with the volume of cloggings. Most of the bridges had a slope close to 0 % and it is at those slope percentages that the biggest and lowest volumes are faced. The normalized volumes don't seem to reveal any difference. Absolute values were also considered in the analyses but show the same result. The volumes at higher slopes are not more frequently higher. Slope doesn't seem then to be a cause of higher clogging volume.

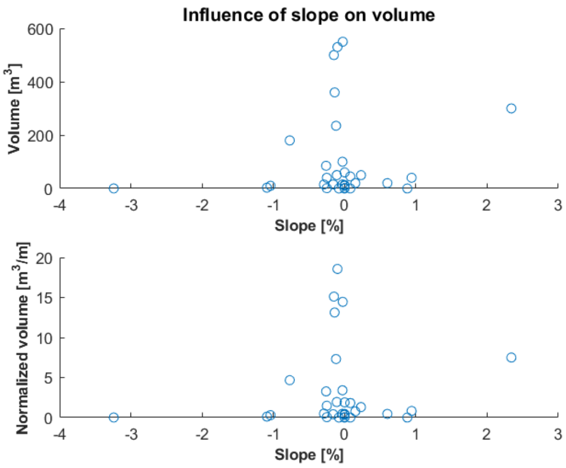

Figure 3.41: Slope and volume

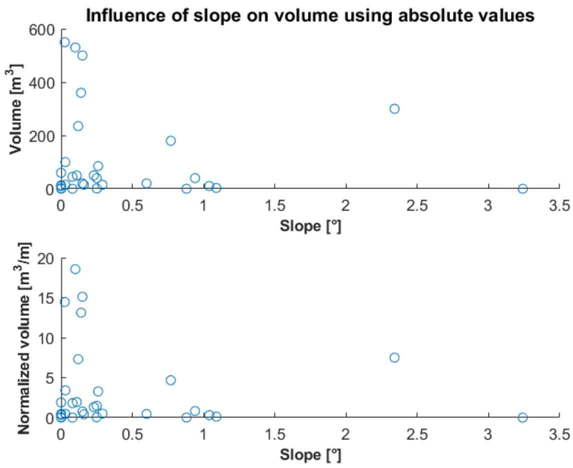

Figure 3.42: Slope in absolute value and volume

Angle Similarly to slope, angle with river was studied using both original and absolute values. Figures 3.43 and 3.44 represent that. A huge proportion of angles close to 0 °have a volume below 100 m^3. However, the biggest volumes appeared also when the angles were less than |10°|. This could be because an angle close to 0 °favorises the location on the whole width of the structure. This will be studied later in paragraph 2.1.5. As for the bridges with an superior angle than |10°|, some of them had an important volume while other didn't. This doesn't allow to make the conclusion that higher angle values cause higher volume of debris.

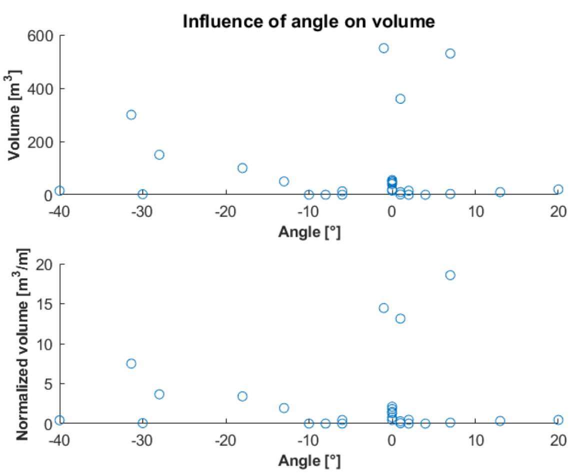

Figure 3.43: Angle and volume

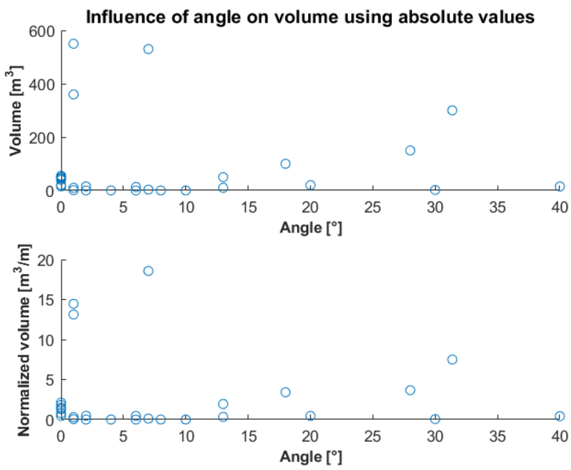

Figure 3.44: Angle in absolute value and volume

Thickness At the beginning of this project, thickness was viewed as one of the major influencers of clogging. Indeed, it seems likely that the higher the thickness, the greater the surface of the bridge obstruating the flow. Figures 3.45 and 3.46 tend to show otherwise. Under pressurized and mixed conditions, a lot of the higher thicknesses didn't provoque a large amount of volume. For nearly every range of 20 centimeters between 0.5m to 1.8m, it is possible to find bridges with low and high volumes of cloggings. In the normalized figure, biggest volume in m^3/m tend to move slightly towards thicker decks but the bridges with low volumes have also thicknesses above 1m. A minimal value of thickness allowing to have a very low volume is not possible to deduce from this data as not enough volumes had below 0.5m thickness which is quite understandable considering the type of structure.

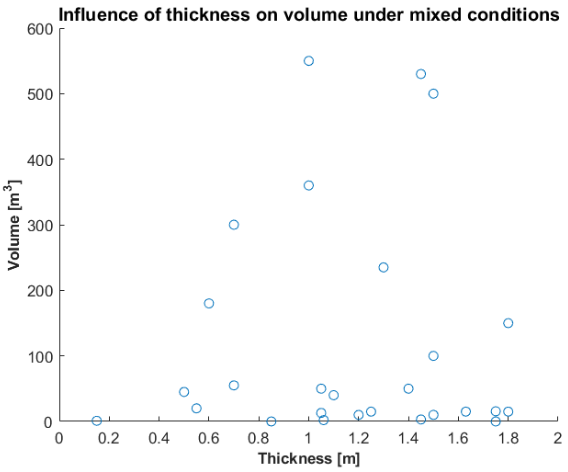

Figure 3.45: Thickness and volume under mixed flow

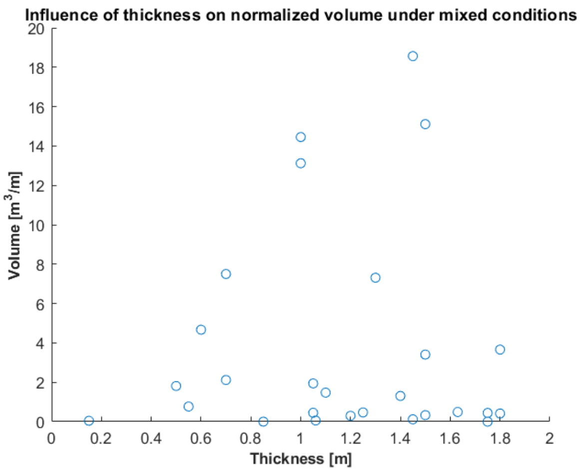

Figure 3.46: Thickness and normalized volume under mixed flow

Height under deck This parameter represents the difference of altitude between the lowest elevated part of the thickness of the bridge and the river bed altitude. It can play an important role in the floodings as this parameter will influence the flow conditions under the bridge. A free surface flow has more chances to occur when the bridge is highly elevated with a thickness that is not too important. It was seen just before that thickness didn't seem to play a role in the cloggings. Thickness is an indirect factor of height under deck, so maybe its role is observed indirectly. Figures 3.47 and 3.48 show the evolution of volume of debris with this parameter. It is observed that most of the deck bridges are in between 4 and 5 meters above the river bed, taking into account the bottom of the thickness as a reminder. When the height above deck is lower than 3.5 meters, some high volumes are observed but it is also the case for heights of around 4.5 meters and even 6 meters. The important disparity of the results make it difficult to advance any conclusion. This parameter would be probably better if analysed in correlation with water height.

Damage The case of damage is interesting as in this one, volume is used as a cause of another parameter and not the opposite. The idea is to view if cloggings with high volumes

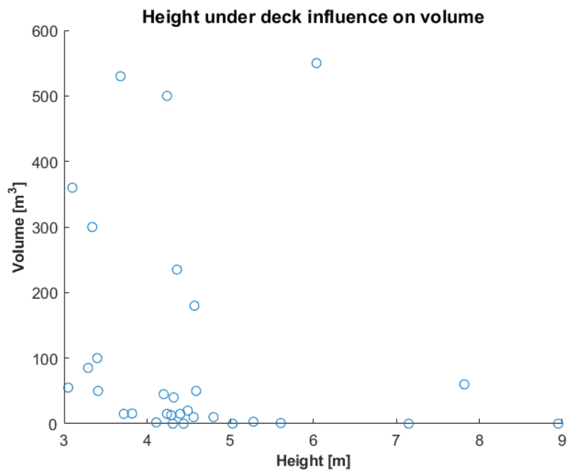

Figure 3.47: Height under deck and volume

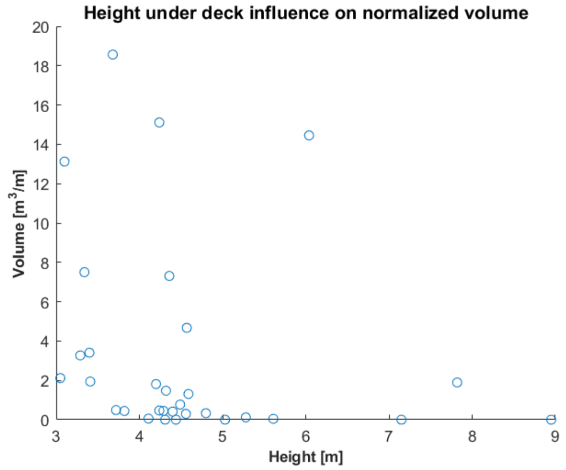

Figure 3.48: Height under deck and normalized volume

tend to damage more the structures or not. Based on figure 3.49, it is possible to see that 5 out of the 7 bridges that had 180 m^3 of clogging or more faced strong damages. The highest volume is the only one to have completely damaged the structure, which in this case lost a pile and then its stability. Only one exceptionnal bridge had only slight damages after really high volumes. When the amount of volume gets around 150 m^3 or below, way more bridges face no damage or only slight damages. This could indicate that starting a volume of clogging of around 200 m^3, the probability to see strong damages on the bridge is increased a lot but when it is below this value, all of the scenario between no damage and strong damage are possible. This suggests that damage can also be influenced by other parameters than volume of clogging. One of this parameter could be the water height and will be analysed later. **Ruiz-Villanueva and al. 2014-1**

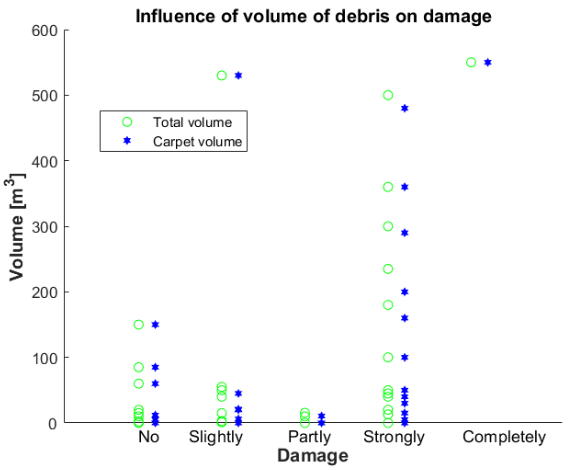

Figure 3.49: Volume and damage

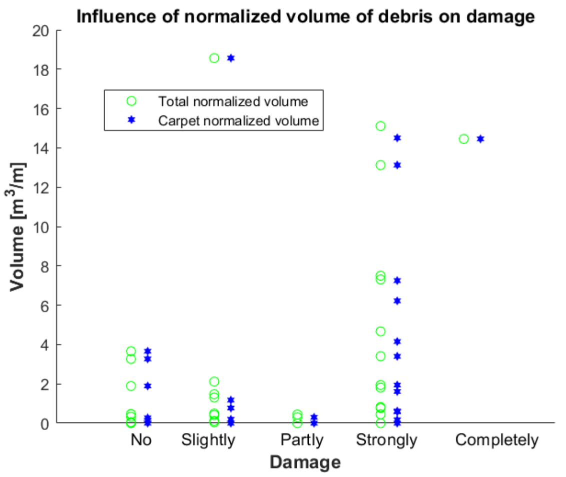

Figure 3.50: Normalized volume and damage

2.1.3 The case of piles

Piles are the other parameters that were excpected to be a source of clogging at the beginning of this project. Multiple scenarios of correlation are possible as piles themselves have different aspects to treat.

Number of piles The influence of number of piles on the amount of volume clogged is shown in figures 3.51 and 3.52. It had already be seen that 3 bridges didn't face any clogging while having 0 pile. Among the other bridges without pile, 3 of them didn't have a precise enough estimation of their clogging to be considered. The remaining bridges in that category have cloggings of 1 m^3 (particular case of a trunk blocked without causing a clogging with it), 10 m^3 and 300 m^3. This last value looks like an extreme case considering all of the other situations faced really low volumes. Among the bridges that were decided to be left without analysis due to their lack of precision, they were estimated to have cloggings of 15, 60 and 120 m^3 respectively. Even if the values are not precise, it shows that bridges without piles shouldn't be linked too early with a clogging volume close to 0 m^3. However, the trend for bridges without pile to have a lower volume seems real.

As for the bridges with at least 1 pile, it seems that bridges with really high volumes (above 300 m^3) had always at least 2 piles. The biggest volume accumulated had 3 of them. The carpet volumes don't seem to indicate a difference of jugement. The normalized volumes tend to show a trend in which the volumes in m^3/m are increased starting 2 piles, but reduce the importance of the bridge that had the biggest volume. This bridge, in reality, lost one of its piles during the events and the clogging was stabilized with 2 piles instead of 3. The amount of bridges with 1 or 2 piles being quite close, it is possible to assume that a bridge of 2 piles has a bigger clogging probability than a bridge of 1 pile, which also has a bigger clogging probability than a bridge without pile. At more than 2 piles, it is not possible to conclude due to the low amount of bridges in that situation.

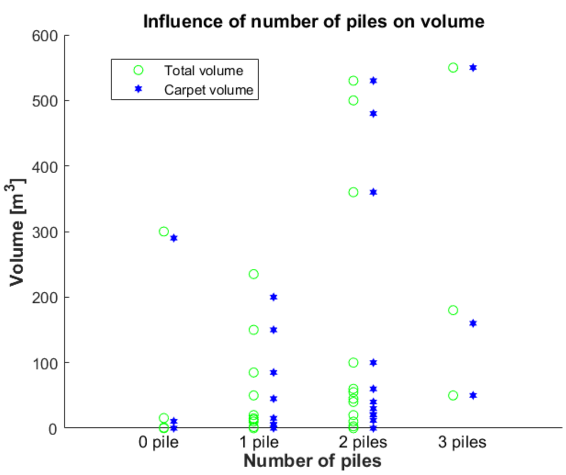

Figure 3.51: Number of piles and volume

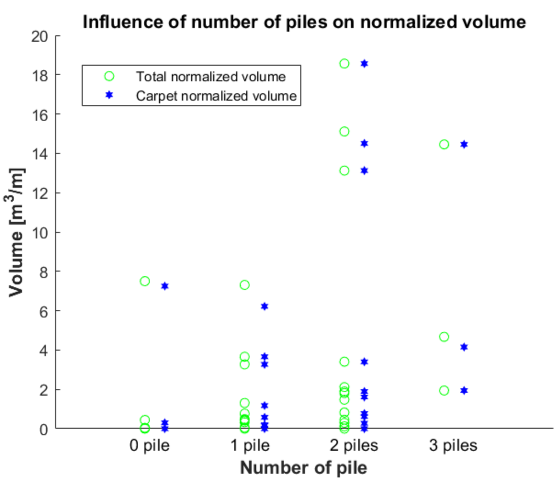

Figure 3.52: Number of piles and normalized volume

As the piles are not interfering the same way during the events, more figures are presented to an idea of the impact of the piles under pressurized/mixed or free surface flow. Indeed, the way piles can obstruct the flow is usually different depending on the flow condition. If the flow is at free surface, the pile are the only responsible of the osbtruction of debris, which should increase the probability of clogging as well. In the case of mixed conditions, the piles should have less effect on the clogging as the water height is higher than them, potentially reducing the amount of debris clogged in the piles.

This is why figures 3.53 and 3.54 are differentiating the two cases. In figure 3.53, total volume of clogging is displayed while assuming pressurized or mixed conditions, when the piles should have a reduced effect. Figure 3.54 is focusing only on a free surface flow. Considering that normalizing the volumes had a significant impact on bridge having a peak volume as well as condensing the volumes of 1 pile, the graphs are showned in normalized conditions. The first figure looks really close to 3.51 as only a few bridges were actually under free surface conditions. The second figure isn't able to show that the presence of pile increases the amount of debris clogged. Indeed, the biggest volume appears when 1 pile is under the bridge. The case of 2 piles shows a volume up to 2 m^3/m but also a volume of 0 m^3/m. The quantity of cases studied here is too low to adress any conclusion as the results diverge.

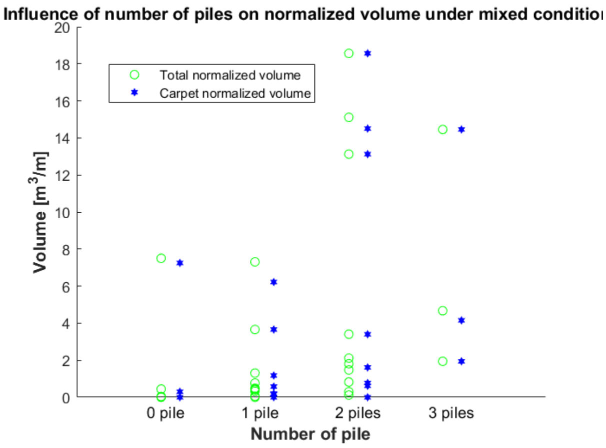

Figure 3.53: Number of piles under mixed flow and normalized volume

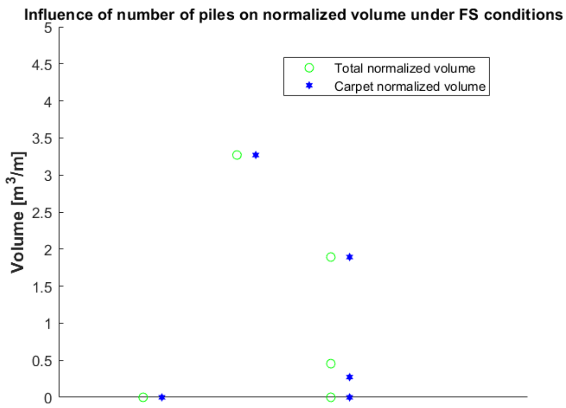

Figure 3.54: Number of piles under free surface flow and normalized volume

Distance between piles If the increasing amount of piles showed an increasing probability of clogging, it can be directly a consequence of the distance between piles. Indeed, bridges without piles tend to have larger distances that allow to let the debris pass under the deck of their bridge. Figures 3.55, 3.56 and 3.57, 3.58 show the effect of the distance between piles respectively under pressurized/mixed conditions and under free surface flow. **Schmocker 2011**, **Ruiz-Villanueva and al. 2017**, **Ruiz-Villanueva and al. 2018**

In the case of mixed flow, it is noticed that most of the bridges tend to have a distance between piles in between 5 and 10 meters. When the distance between the piles is fewer than 8 meters, the volume is more frequently higher than when the distance between piles is higher than 10 meters. Out of the 18 bridges having a distance between piles higher than 10 meters, 6 (=33%) had a volume of at least 40 m^3 while for the 10 bridges with a distance between pile below 8

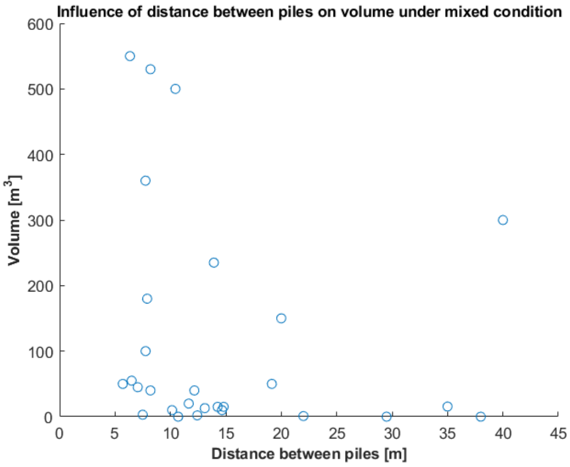

Figure 3.55: Distance between piles and volume under mixed flow

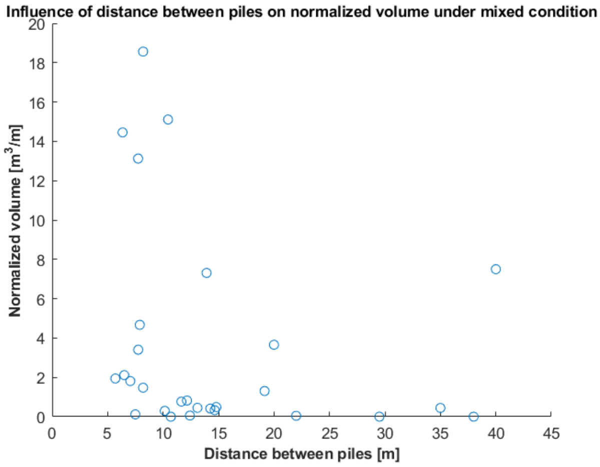

Figure 3.56: Distance between piles and normalized volume under mixed flow

meters, 9 of them (= 90%) have reached a volume of at least 40 m^3. When looking at higher volumes, 50% of the bridges with a distance between pile lower than 8 meters have accumulated more than 100 m^3 compared to only 22 % (4/18) of the bridges with a distance between pile of above 10 meters. This indicate the presence of a minimal distance value responsible for the clogging of the bridges. Considering that no bridge was under 8 or 10 meters precisely, it is difficult to estimate that distance. The normalized values shown in figure 3.56 reinforce that impression.

About the distances between piles when free surface is observed, a volume of 60 m^3 and another one of 0 m^3 were found in a clogging having a distance between pile of around 8m. Another little clogging of 20 m^3 also appears for a 10 meters distance. Those values are difficult to interpret as there are only 3 of them. Free surface being also influenced by the pile width, there can't be conclusions made yet about this specific case.

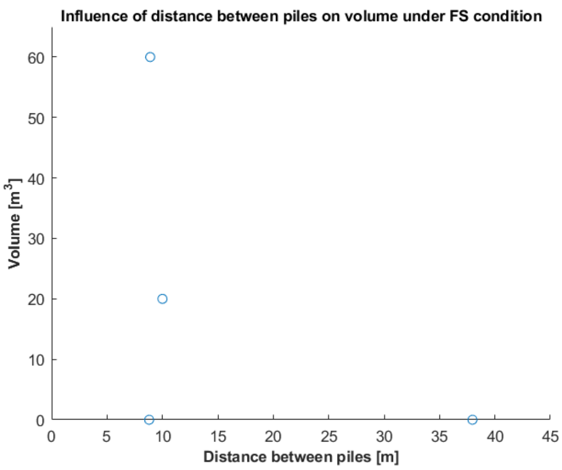

Figure 3.57: Distance between piles and volume under free surface flow

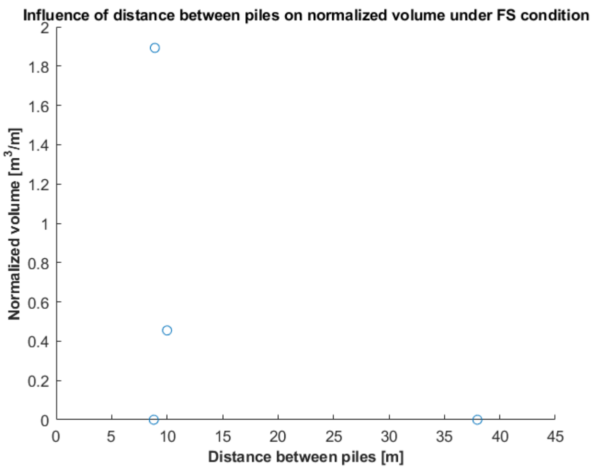

Figure 3.58: Distance between piles and normalized volume under free surface flow

Pile shape The case of pile shape is studied in a similar way. A look at figure 3.59 allows to notice an important amount of volume clogged when the pile is round nosed and in pressurized/mixed conditions. However, there were also more bridges studied having those kind of shapes and sharp nosed bridges are less common. Comparatively, the 7 lowest volumes registered for round nosed piles are higher than for the 7 sharp nosed volumes that had a clogging. This could also indicate that sharp nosed are better at evacuating the debris than round nosed. The examples of square nosed and circular shapes are in too low quantity to really evaluate the influence of the shape. Those situations can be really situationnal. The normalized vision studied in figure 3.60 doesn't give new information about the influence of the shape of the pile.

Regarding the free surface flows, all of the bridges under that condition were of round nosed shape, as shows figure 3.61 ans 3.62. It might be a coïncidence. The volumes showed having important variability, nothing can be concluded on that point. **Ruiz-Villanueva and al. 2020**

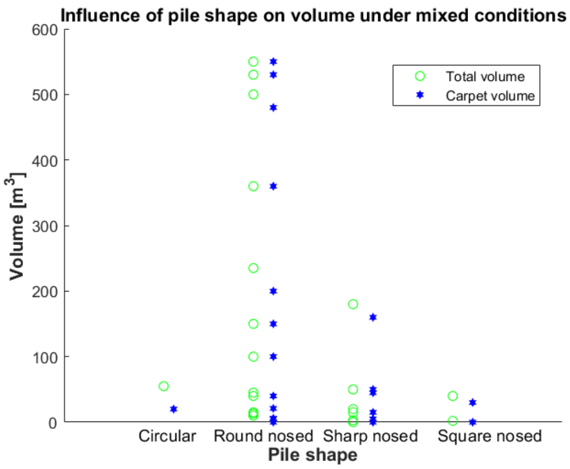

Figure 3.59: Pile shape and volume under mixed flow

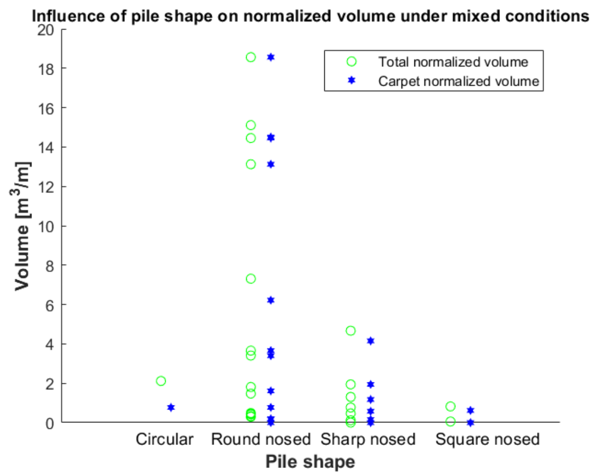

Figure 3.60: Pile shape and normalized volume under mixed flow

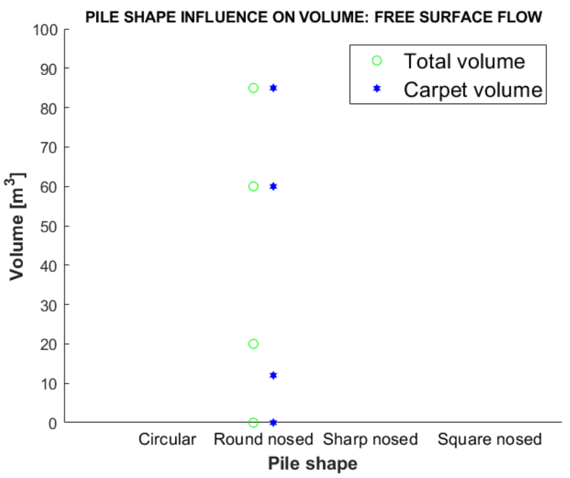

Figure 3.61: Pile shape and volume under free surface flow

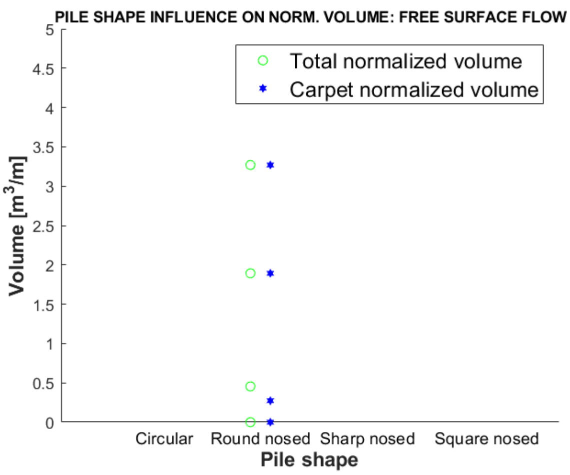

Figure 3.62: Pile shape and normalized volume under free surface flow

Pile protrusion The influence of protrusion on total and normalized volume has been analysed in figures 3.63 and 3.64. As there is only one case under free surface with a protrusion known, this scenario is analysed whatever the flow condition is. The figures highlight an increased amount of volume for protrusion of 0.5 m. The normalized graph seems to even more emphasize this aspect as the higher values of protrusion are not decreasing in term of volume/m (the plot is flattening). As there are only 3 examples in that case, it may be a coincidence. Furthermore, when looking back at figure 3.16, the values of 0.5 meters are actually the ones that were guessed by an on site measurement that couldn't allow a precise measurement. This means that the value was guessed from a close range parallel to the bridge. Even if it is not entirely incorrect, having all those values at 0.5 meters seems suspicious and it reduces the fiability of the information.

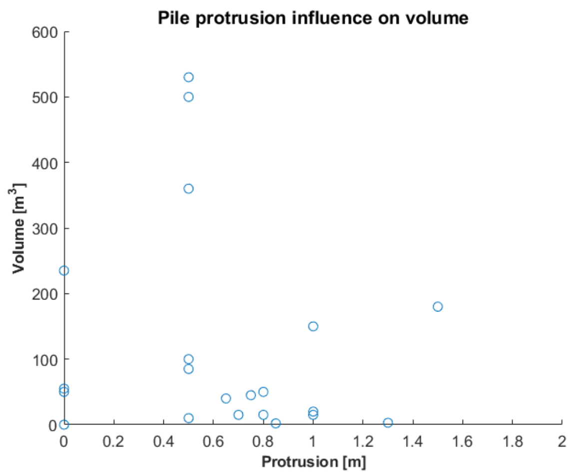

Figure 3.63: Protrusion and volume under mixed flow

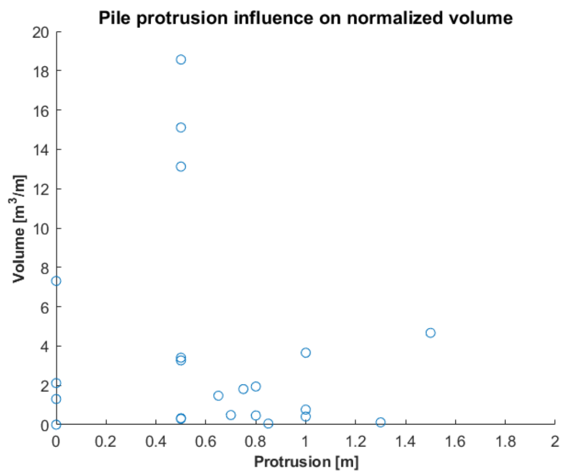

Figure 3.64: Protrusion and normalized volume under mixed flow

Pile width The last part of the piles studied is the pile width. this parameter seems quite important regarding to floodings as the wider piles are, the more they can obstruct debris. Figures 3.64 and 3.63 both show the influence of pile width on volume. Both were analysed without restrictions of type of flow as the amount of cases with fiable data under free surface flow was too low. It is because the width of the piles of some railway bridges, which are most of the time at free surface, were not precise and then not considered. When looking at the mentionned figures, pile width doesn't seem to play a significant role in the accumulation of volumes. Most of the piles are around 1 meter wide. For lower values, for example 0.8 meters, different amount of volumes (from 0 m^3 to 500 m^3) are faced. A similar observaion is made for volumes up to 1.4m. The only values of pile width that seem having an influence are at above 2 meters wide. If the data from the imprecise railway bridges was kept, assuming a 2 meters wide (instead of 2.7m) piles, this tendency would have been increased but other values would have been added and potentially false the results for piles not as wide. This highlights the importance of the definition of hypothesis and the awareness regarding its consequences.

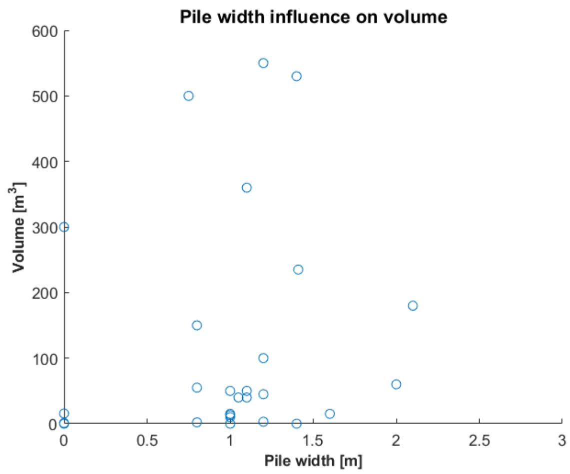

Figure 3.65: Pile width and volume

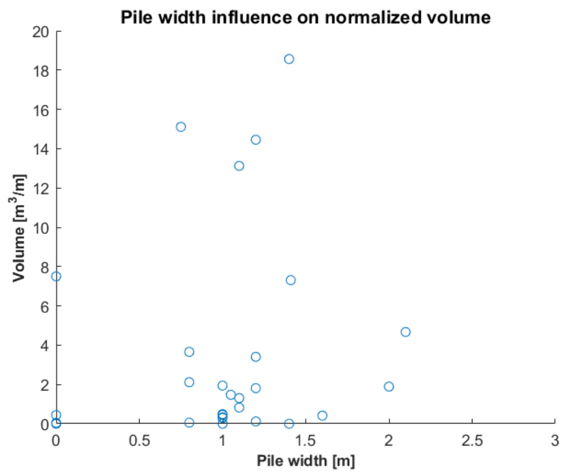

Figure 3.66: Pile width and normalized volume

2.1.4 Main hydraulic elements

Type of flow The previous graphs based on type of flow conditions already showcased the amount of bridges that were clogged while being under mixed conditions. Figures 3.67 and 3.68 suggest again this idea that mixed conditions are an important factor of the amount of volumes of clogging created. Although it doesn't guarantee that a clogging will appear as some bridges in mixed conditions faced low volumes of debris, nor is it a necessary condition on clogging as some bridges under free surface and pressurized flow were clogged, there is the fact that the biggest amount of volumes have all faced mixed conditions. Type of flow is at its best studied along another paremeter mentionned in the previous section which is the height above bridge surface.

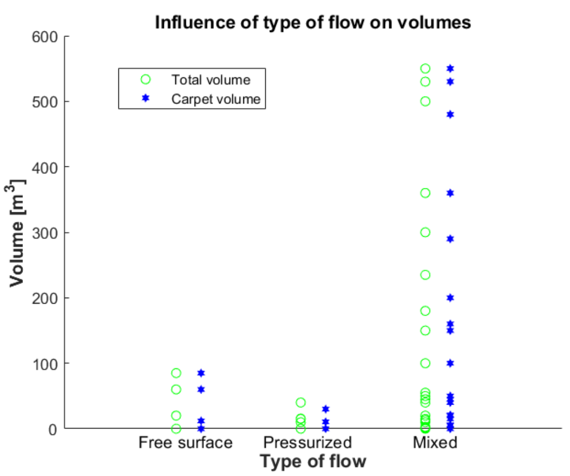

Figure 3.67: Type of flow and volume

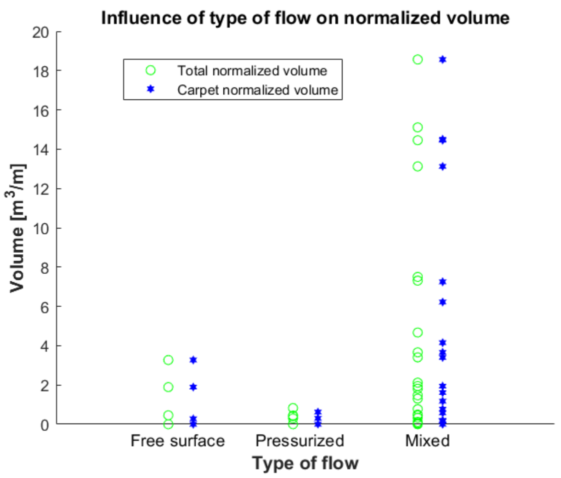

Figure 3.68: Type of flow and normalized volume

Water height above bridge surface Prior tests on structural alone parameters on the vertical axis (height under deck and thickness) couldn't really show influences about accumulation of debris. Howeve, the type of flow suggests that hydraulical phenomenons have an influence on accumulation on debris. The following figures 3.69 and 3.70 try determine the influence of hydraulical phenomenons by displaying the water above bridge surface in influence with volume accumulation. It allows to consider only mixed flow with the positive values, but also determine if for those mixed flows, higher elevated water depth have a bigger impact or not. It also showcases the impact of pressurized and free surface flow thanks to negative values.

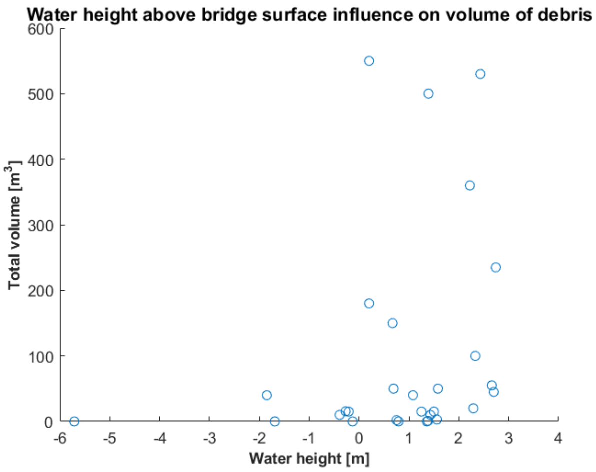

Figure 3.69: Water height above bridge surface and volume

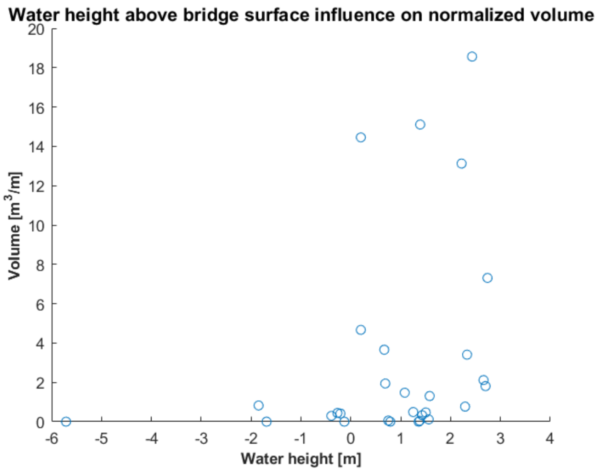

Figure 3.70: Water height above bridge surface and normalized volume

It can be observed that negative amount of values (not mixed flow) are cause of lower volumes, as it was explained sooner in this project. Regarding mixed flow, it seems difficult to determine an influence of the water height as the biggest volumes have varying water heights between 0 and 3 meters. Multiple lower volume bridges also have water heights in that interval, which leads to believe debris accumulation are not a consequence of water height above surface.

Water height above bottom of thickness Trying to take into account thickness one last time, it is now possible to mix it with water height and consider only the water height above the lowest elevated part of the bridge deck. This allows to have both the thickness of the bridge and the water height above the bridge combined in the influence on volume accumulations. Those are represented in figure 3.71 and 3.72.

For lower volumes, there seems to be a tendency that starting 3 meters of thickness and water height combined, volumes tend to be higher. It is especially noticeable on the normalized graph. It is more difficult to admit for biggest volumes as 2 of them have reached over 200 m^3 of volume with around 1 meter combined thickness and water height above bridge. A particular case is also shown with a very low volume despite huge water height.

2.1.5 Other comparisons

Damage was previously linked with volume. Figure 3.73 is linking damage to a hydraulic component : water height above bridge surface. Positive values refer to mixed conditions. Negative

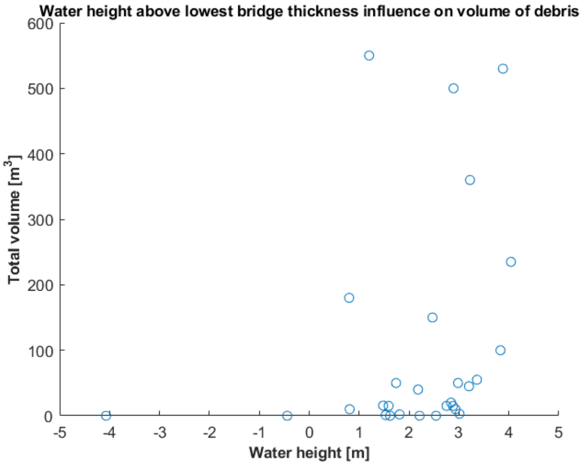

Figure 3.71: Water height above bridge lowest thickness and volume

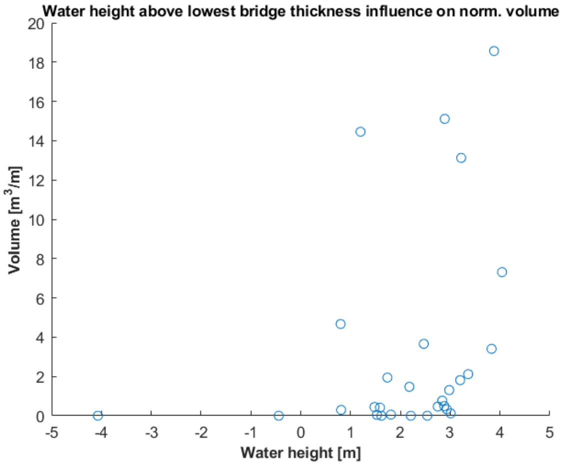

Figure 3.72: Water height above bridge lowest thickness and normalized volume

values could refer both to pressurized or free surface conditions, as it is dependent on the thickness which is not taken into account. It is observed on the figure that negative values are not easily linked with low damage. Only a few values below 0m were registered and most of them are associated with a partial damage. For really low values under 1m, there are two bridges involved and one faced no damage, the other one faced strong damage. When water heights increase, both slightly and strongly damage are increasing, meaning that there is not a greater damage under greater water height conditions.

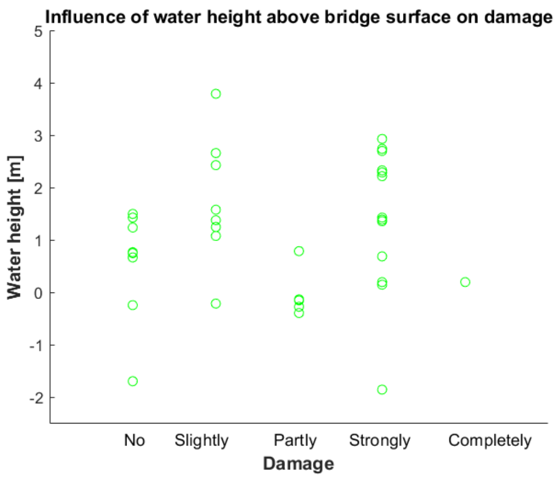

Figure 3.73: Water height over surface influence on damage

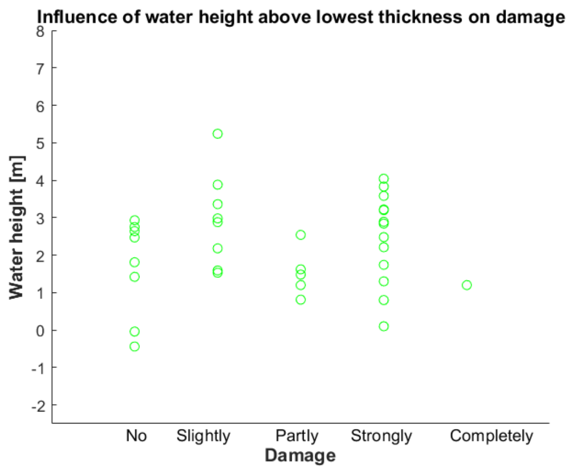

Figure 3.74: Water height over lowest thickness influence on damage

To take into account the thickness, the same comparison is made using the water height above deck, representing the water height above bridge surface + thickness of the bridge. Results are given in figure 3.74. There are no significant changes in the interpretations. Similar lines above the x axis are created but taking into account the thickness simply condenses the graph and the values. There is then no real way to associate damage of the structure with water height above the thickness of the bridge. It is likely thet damage should also be considerated against type of handrail and material, which are two parameters that were not studied further in this project. The definition of damage taking into account the damage of the handrail, it could have changed the interpretation to pay attention to those factors. In that case, damage quantified by "No", "Slightly" and so on are considering implicitely the damaged on the handrails when there were which troubles those results. Also, structural damage can also be a consequence of the type of road surface, presene of pavements or not and also on the foundation of the bridge. All of these remarks make it difficult to use other factors than debris volume causes of damage.

The upstream river shape was mentionned to be interesting to study to consider its consequence along the location of debris at structure. The different possibilities of deposit while coming from a certain river shape are shown in figure 3.75.

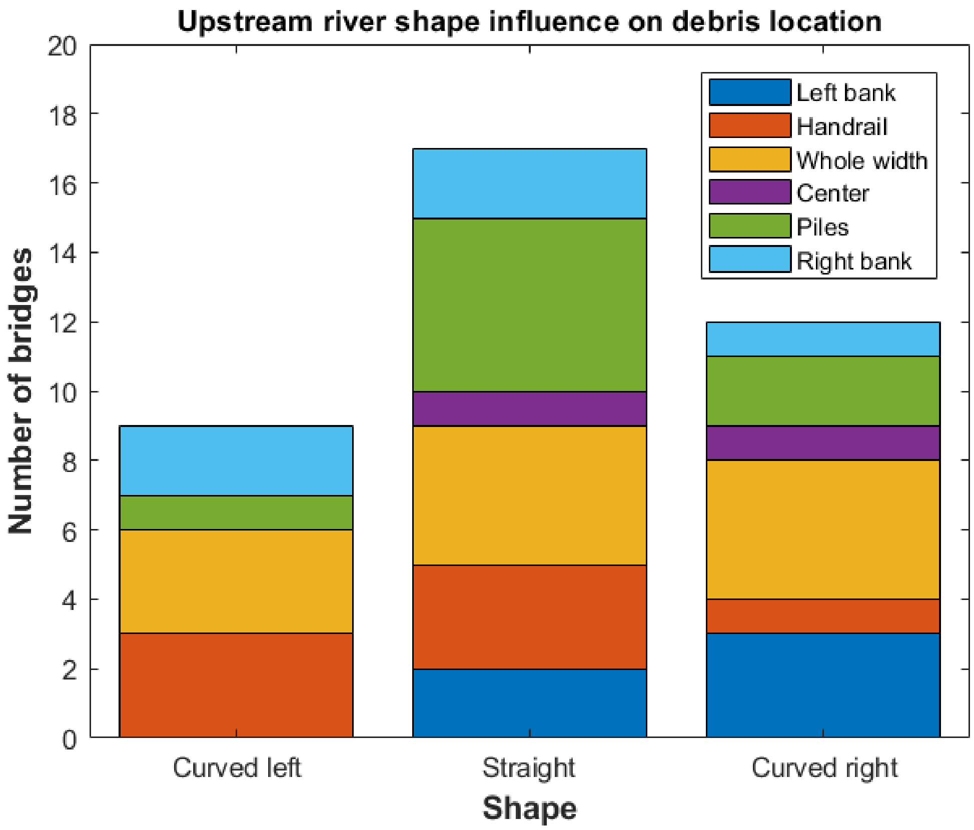

Figure 3.75: Upstream river shape influence on debris location

The main noticed thing is that a straight upstream shape tends to create more piles clogging that the other upstream shapes. Indeed, 5 out of 8 (=62.5%) of those specific carpets are coming after a straight river shape. The second noticeable effect is that the coming curved position tend to be followed by deposit on the opposite bank, i.e. a curving right upstream shape tends to deposit the debris on the left bank and vice versa. Indeed, under curved left upstream shapes, no deposit on left bank was found out of 5 possible cases and under right curved shape, only 1 out of 5 deposit on right bank was found. Most deposit on left bank occured after a curving right shape and most of the right bank deposits were found after a curved left shape. As for the whole width, no upstream shape condition seems to have an influence on it.

2.1.6 Conclusion on two dimensional parameters

This section established analyses between 2 parameters to see if there was any correlation between them.

It was first observed that higher cloggings tend to have their debris locate on the whole width of the river or on the banks. Piles, handrail and center cloggings were minimized in comparison. It was also shown the Piles and handrail total volume differ quite a lot from the carpet volumes. Carpet length, width and height were found more proportionnal to carpet volume than total length, width and height were on total volume.

For the structural parameters, the opening shape looks to have an influence on the accumulation of debris. Arched bridges were indeed less clogged than rectangular bridges, without knowing if it was a causality or simple correlation. The slope and angle showed no influence on the amount of volume accumulated. Thickness, while considering mixed or pressurized conditions, and height under deck were not parameters that seemed to have an influence on clogging. The damage was in slight relation with volume of debris. Most of the cloggings with high volume of debris caused important damages but for volumes lower than 150 m^3, no correlation between volume of debris and damage was seen. Damage was not influenced by water height as well.

As for the case of piles, the number of piles is considered as having a noticeable influence of the amount of volume blocked in the clogging. Indeed, most of the bridges without pile had really low cloggings. The biggest volumes of above 300 m^3 were also observed when at least 2 piles were present. Dstance between piles seems also to be a parameter causing an important amount of debris, especially when the distance is lower than 8 meters. Regarding pile shapes, round nosed ones tend to accumulate more debris than the others. Pile protrusion and pile width didn't have significant influences on the total amount of volume in the cloggings.

For the hydraulic parameters, mixed flows suggest an increased probability of high volume cloggings. Lower volumes are not affected really much by the type of flow, though. Water height above bridge surface seems to have little influence on amount of volume in the clogging. When the water height above bottom of thickness is considered, a small tendency appears that higher water heights than 2.5 meters increase slightly the amount of volume in the clogging.

As for the location of debris at the structure, they tend to be in correlation with the upstream river shape. A curving left or right upstream shape has very few chances to provoque a clogging on respectively the left bank and right bank. Pile carpets were also affected by the upstream river shape as they were more frequent when the debris were coming straightly.

3 Multi parameters analysis

This section establishes the links between clogging and the parameters that were established as potentially dominant in the previous section. To realize a multi parameters analysis, a first section is used to compare the cloggings with really high and really low volumes of debris. This comparison should determine which are the dominant factors in the formation of cloggings. A second section is dedicated to the analysis of Verviers with the display of its bridges based on their abscissa curvilinear. Interpretations are made based on the data of all the bridge in that municipality.

3.1 Comparisons between high and low carpet cloggings

This section compares the bridges that are considered having high and low volumes of cloggings. 8 bridges analysed having at least $150m^3$ are grouped into the category "high volume bridges". 8 other bridges analysed having the lowest volumes, i.e. under 5 m^3 of volume of clogging are grouped into the category "low volume bridges". This allows to have enough bridges compared as well as not taking the bridges having more common cloggings.

The parameters subject to be influent on the total volume are the The opening shape, the number of piles, the distance between piles and the water height above the bottom of the thickness of the deck (further used following the form H.A.B.T). The type of flow isn't considered here as it is indirectly taken into account in the H.A.B T parameter. If the parameters are defined as having a criteria 4 of precision, they are not considered.

The proceeding will be the same as in the previous section. Parameters are compared to the volume but only focusing on the biggest and lowest ones. This allows to generalize data about mean values, median and standard deviation more effitiently. As the graphs would be the same here as in the previous section without the bridges ranges in between, they are not repeated here. A global table in figure 3.76 recapitalizes the main results obtained.

The main characteristics observed in the previous analyses are shown in this very specific study. The extremely "high volume" clogging have very different characteristics than the "low volume" ones. First, the amount of arched bridges is two times higher in the bridges that dit not cause any clogging or nearly (<5 m^3). Indeed, half of those bridges were arched while only 1/4 of the bridges clogged were rectangular. Furthermore, the amount of piles in clogged bridges is higher than in no clogged bridges who tend to have 0 pile (50% of the cases) or at least not more than 1 pile (75% of the cases). In the clogged bridges, 62.5 % had at least 2 piles.

Distance between piles was analysed taking into account the number of piles. A case with all of the bridges was studied, followed by a case with only bridges having at least 1 pile and finally an analysis of bridges with at least 2 piles. Considering the amount of bridges without piles for the no clogged bridges, it is not a surprise to find a mean value of around 20 m and a high standard deviation of 12.87m. The case of at least 1 pile is a bit more interesting to study and shows that the bridges without clogging had a higher minimal value of distance and a higher median that bridges clogged. On of the bridges clogged had a distance between piles of 20 meters, suggesting that this parameter might not be as important as it seems in clogged debris. This bridge is a particular case as it is located on the side bank and debris are mostly under the surface of its bridge, which is why the distance between pile isn't really effective to reduce the amount of volume. However, it is also the bridge that got the lowest total volume in its clogging (150 m^3). When only bridges with 2 piles are considered, the values of distance are a bit closer and the median is around 8 meters in both cases. The results of only 2 bridges for the no clogged bridges are difficult to interpret due to the lack of bridges considered. The minimum value is however obtained in the clogged bridge that had the most volume (550 m^3).

Regarding height above bottom thickness, the tendency to have a higher value for high volume bridges is confirmed. The mean value is of 2.6m and the median a bit less than 3 meters with a low standard deviation for clogged bridges. It is way higher than the 1 m average and 1.7m median values of the unclogged bridges who have a higher standard deviation, though.

Those results tend to confirm the analyses realized during this project comparing all of the bridges together. The type of opening shape may be the only one still not certain to have a direct consequence on the clogging as there were along the Vesdre simply more rectangular shaped bridges and some of the arched bridges had 0 pile which is one of the most important parameter it seems. The distance between piles, when there are, and height above the bottom thickness play a major role together along the number of piles in the forming a cloggings.

A scenario to explain this would be that when the water level is increasing, debris start to accumulate first due to the presence of the pile because they are in the way. As the water level is raising, the clogging is intercepting more debris and create a bigger obstruction causing a snowball effect of accumulation of debris. If the distance between piles is low, the probability for debris to hit them is increased. When the water level is high enough, the role of the thickness of the bridge is under action as it is also blocking the floating debris. As most of the debris are trunks, it is quite easy to get blocked even by a small thickness. The handrail could play a role in that situation for a short period of time if it is able to handle the discharge and debris going fast at it. As floating debris are not all the time exactly at the top surface water but are moving in a disordonned way due to the high discharge, when water height are above the thickness, debris still get stucked in it and reinforce the clogging. **Schmocker and al. 2013**

The clogging then formed is blocked by the thickness and slightly goes above it with some residual debris and is also blocked under because of the form of the debris accumulated more upstream and who are usually at a lower level that the height of debris eally close to the bridge. When the water level decreases, the presence of piles prevents the debris from passing below the deck. It could be due to the distance between pile or simply because the discharge is lower and the clogging is compact which is then difficult to move. It seems then easier for bridges without piles to let go the debris under after catching them with their thickness.

Dominant parameters	Bridges with more than 150 m^3 of cloggings	Bridges with less than 5 m^3 of cloggings
Opening shape	25 % Arched 75 % Rectangular	50 % Arched 50 % Rectangular
Number of piles	12.5 % 0 pile 25 % 1 pile 37.5 % 2 piles 25 % 3 piles	50 % 0 pile 25 % 1 pile 25 % 2 piles
Distance between piles (all bridges)	Mean value : 14.32 m Median : 9.32 m Standard deviation : 11.28 m Min value : 6.35 m Max value : 40 m	Mean value : 20.86 m Median : 17.21 m Standard deviation : 12.87 m Min value : 7.5 m Max value : 37.97 m
Distance between piles (at least 1 pile)	Mean value : 10.65 m Median : 8.2 m Standard deviation : 4.8 m Min value : 6.35 m Max value : 20 m	Mean value : 9.855 m Median : 9.75 m Standard deviation : 2.15 m Min value : 7,5 m Max value : 12.42 m
Distance between piles (at least 2 piles)	Mean value : 8.13 m Median : 7.9 m Standard deviation : 1.47 m Min value : 6.35 m Max value : 10.45 m	Mean value : 8.15 m Median : 8.15 m Standard deviation : 0.91 m Min value : 7,5 m Max value : 8.8 m
H.A.B.T	Mean value : 2.64 m Median : 2.89 m Standard deviation : 1.25 m Min value : 0.8 m Max value : 4.04 m (1 bridge not considered (very imprecise))	Mean value : 1.02 m Median : 1.71 m Standard deviation : 2.29 m Min value : -4.07 m Max value : 3.01 m

Figure 3.76: Upstream river shape influence on debris location

3.2 Focus on Verviers

City of Verviers was sadly hardly hit by the floodings. A lot of successive bridges were damaged and faced cloggings, but some other bridges remained with few damages. Under a discharge that should be constant through the city, it is possible to analyse the different factors that caused the formation of embacles now that main dominant parameters are known. The encoding of the parameters in Verviers was also very precise.

This focus will try to analyse the chaining of clogging of bridges using the curvilinear abscissa to show the real distances between the bridges. Dominant parameters will be shown on the same graph : total amount of volume, water depth and bottom of thickness of the bridges are represented. An indication about the number of piles will be given on the top of figure 3.77 in parenthesis.

To understand better this figure, let's try to analyse the path of the water. It arrived in Verviers from a rural area from which few data was available. At the very entrance of Verviers, a lot of volume is observed in a bridge that faced a water height way above the bottom of its thickness. Huge amount of volumes are there kept by this bridge that had 2 piles and a rectangular shape. After that bridge, a short distance is covered without having a lot of data. Some bridges are then facing some deposit in lower quantity. This figure indicated that after a huge volume blocked, the following bridges tend to accumulate less volume of debris.

When a bridge with 3 piles is reached, a bigger amount of volume is suddenly observed. This is not a surprise given the previous analyses. After that, a bridge under free surface flow doesn't seem to block any volume of debris. This bridge also had 0 pile, reinforcing the importance of not having any pile in this kind of events. A few bridges are passed by the water easily as they don't have any pile. The only obstacle was a bridge having 2 piles, suddenly increasing the probability of getting caught in a clogging. Verviers center is after that left without too much damage on their bridges given the circumstances.

Another distance is passed without having trustful data to analyse it. At the end of Verviers, a first bridge is getting obstruated by an important clogging resulting probably of a huge water height compared to the height of the bridge. This bridge having 1 pile, it could still allow some debris to pass by... until the biggest bridge analysed in this project arrive. With its 3 piles and 6.35 distance between them, there was no chance for the debris to go through. Actually, some did after the bridge got broken - the only bridge in the Vesdre river to lose a pile, allowing a little bit of movance even though the carpet was already too strong to be removed. Finally, other bridges with 2 piles and huge water heights blocked modrate amounts of volumes.

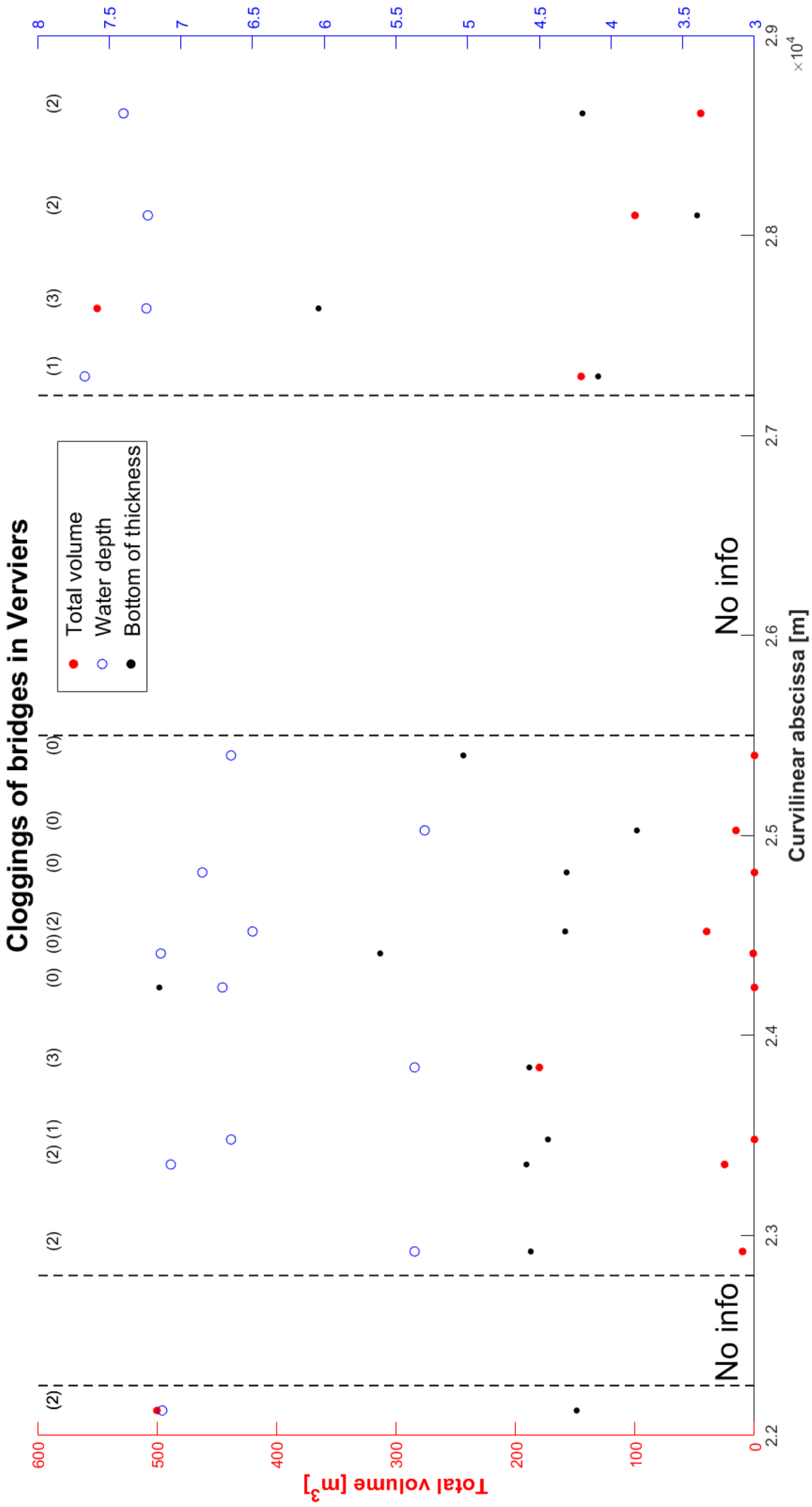

Figure 3.77: Verviers during floodings

Chapter 4

Conclusion

The present master thesis studied the characteristics of the bridges that were responsible for the accumulation of volume of debris. It analysed the different factors that were responsible for cloggings and managed to determine which paramters were the most important.

This Master thesis started by explaining the different parameters that required to be observed at least once. A lexicon and detailed methodology were given for a good understanding. A fiability assessment was created in order not to create misinterpretation of results.

The second chapter was sectioned in three different categories. The first one analysed the parameters studied of the bridges for which information had been found. Multiple graphs were made in order to see what parameters deserved a further discussion. The piles, opening shape, angle, slope, thickness, flow conditons and location of debris were all decided to be analysed in the next section. Handrail material, porosity and height were not more analysed due to lack of diversity in the bridges as well as the abutments and the unregularity.

A next section was used to create relations between the parameters and the volume accumulated in the cloggings. It appeared that piles had an important effect on the cloggings, especially their number and the distances between them. Other parameters of the piles such as the protrusion, width or shape couldn't by correlated sufficiantly to be analysed in more deepness. Angle and slope seemed to have no effect on the amount of volume accumulated. As for hydraulical conditions, they were often related between each other. Mixed conditions proved to be highly correlated with cloggings, which is a consequence of the water depth, the height of the bridge above the surface and the thickness of the bridge. The parameter able to represent all of these characteristics together was the water height above the bottom part of the thickness, which was correlated to the accumulation of volume.

A final section compared the 8 bridges having accumulated the most of debris and the 8 ones that didn't accumulate or nearly not any volume. The distance between piles, amount of pile and water above bottom of thickness were all proven to be factors causing cloggings while the 8 bridges with low volumes analysed tended to have different characteristics about those 3 influent parameters. The conclusion was then made that those 3 parameters have the most importance on the creation of cloggings. Finally, a display of the situaton in Verviers was shown in order to showcase the importance of those parameters along the city.

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