Prototype Development of Knowledge Based Expert System for Groundwater Lowering Method

by

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CERTIFICATION OF APPROVAL

PROTOTYPE DEVELOPMENT OF KNOWLEDGE BASED EXPERT SYSTEM (KBES) FOR GROUNDWATER LOWERING METHOD

by

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ABSTRACT

The purpose of this project is to find the best method among all the methods use nowadays for ground water lowering process by using Knowledge Based Expert System. At first, studies about expert system and the domain which is ground water lowering methods need to be done before all the information about the domains can be programmed into the expert system tool. For this expert system project, the tool or software that is going to be use is CLIPS which is stand for C Language Integrated Production System. A CLIPS is a productive development and delivery expert system tool that provides a complete environment for the construction of rules and object based expert system. Further studies and familiarizing process on CLIPS tool and it's coding and also development of the rules will be done after preparing the input file and information of the various methods in ground water lowering process. Since expert system and CLIPS tool are something quite new to student here, this project is very suitable to expose students to this field. The first part of the project is to search and collect all the information related to the expert system and CLIPS and prepare the input data about ground water lowering methods. The information of the domain will include types of ground water lowering method, the soil condition that suitable for each method, type of structure that are going to be constructed, the effectiveness of each method and the environmental condition. After preparing the information, the next step is to represent the knowledge by using tree method or flow chart to identify the characteristic, types and effectiveness of all information. After that, need to develop the rules of the information before program it into a CLIPS. After complete develop the rules, key in all the information by using specific coding and programming language into CLIPS. Final step is the process of running, checking and correcting of the program. The project is endured by planning the work to be done, doing research on the topic and carry out the project work by using the tools and software.

ACKNOWLEDGMENT

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in His will and given strength, I had managed to complete my Final Year Project. I would like to take this opportunity to extend my greatest appreciation and gratitude to all the people of Civil Engineering Department of Universiti Teknologi PETRONAS for the high commitment and cooperation showed in assists me, to successfully complete the Final Year Project.

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Next, my appreciation goes to my external examiners from Ranhill Construction, Ir. Dr. Hj. Affendi Abdullah, for inspiring me with moral support and encouragement besides giving me a valuable opportunity to venture into a real life project. Not to forget to my internal examiners Miss Niraku Rosmawati Ahmad who had gave me opinions, guidelines and encouragement in improving my project. All the concern, assurances and willingness to monitor my performance had made me more confident and independent in completing this project.

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INTRODUCTION

1.1 Background of Study

1.1.1 Ground Water Lowering Method

Ground water lowering method or in other name called as dewatering process is a procedures or methods that use to manage; control and decrease the level of ground water below the ground and surface water run-off before construction project can be started especially involve the works below the ground. Removal of water from the ground will cause the water level to fall. How quick and by how much the decreasing of ground water level depends on the permeability of the soil. Lowering the ground water will reduce the pore water pressure and hence increase stability and the strength of the soil. These are very important for ease of the workers to run the works involve especially below the ground such as constructing the dam, building the basement or foundation for tall buildings and constructing the underground train's station. There are several method for lowering the ground water level such as deep well system, pumping system, sump pumping, wellpoint system, ejector and many more and the methods and procedures of the systems are very much depend on the site location, environmental condition, types of structures that are going to be constructed, type of ground materials, the effectiveness of each method and other specification such as process to setup the apparatus and system, safety and many more. All the methods used for lowering the groundwater level can be referred at the *appendix 4*.

1.1.2 Knowledge Based- Expert System

Knowledge Based Expert System or simply expert system is a system that uses human knowledge to solve problems that normally would require human intelligence. This system represents the expertise knowledge as data or rules within the computer and the data and information can be called upon when needed to solve problems. Human task is to gather and interpret all information need into system. Knowledge Based system collect the small fragments of human know into a knowledge base that is used to reason through a problem, using the knowledge that is appropriate. The ability of these systems is to explain the reasoning process through back traces and to handle levels of confidence and uncertainty provides an additional feature that conventional programming doesn't have. Expert system are developed via specialized software tools called shells which it comes equipped with an inference mechanism (backward chaining, forward chaining or both) and require knowledge to be entered according to a specified format.

1.1.3 CLIPS Software and Coding

Expert system is actually a conventional programming language such as FORTRAN and C and are designed and optimized for the procedural manipulation of data (such as numbers and array). One of the availability of expert system tools is Clips Software. CLIP S is a productive development and delivery expert systems tool that provides a complete environment for the construction of rule or object based expert system. Clips is being used by over 5,000 users throughout the public and private community including all NASA sites and branches of the military, numerous federal bureaus, government contractors, universities and so on. The features of Clips are:

1. **Knowledge Representation:** Provides a cohesive tool for handling a wide variety of knowledge with support of three different programming paradigms: rule based, object oriented and procedural.
2. **Portability:** Written in C for portability and speed and has been installed on many different without code changes.
3. **Integration/Extensibility:** Can be embedded within procedural code called as a subroutine and integrated with languages such as C, FORTRAN and ADA. It can be easily extended by user through the use of several well-defined protocols.
4. **Interactive Development:** Provides and interactive, text oriented development environment, including aids, on-line help and an integrated editor.
5. **Verification/Validation:** Includes a number of features to support the verification and validation of expert system including support for modular design and portioning of a knowledge base, static and dynamic constraint checking of slot values and function arguments and semantic analysis of rule patterns to determine if inconsistencies could prevent a rule from firing or generate an error.

1.2 Problem Statement

1.2.1 Problem Identification

There are various types and methods in lowering the ground water level for construction project and so on. The methods are exclusion method such as sump pumping, well point systems, deep well systems and other dewatering systems such as ejectors, horizontal well-points, pressure relief wells, collector well, electro-osmosis and so on. The selection of the best method by using Knowledge Based Expert System can help user to easily select the most suitable method for certain condition and location of ground water level and this can save much energy and time instead of doing the research and studies on that. This project of Prototype Development of Knowledge Based Expert System (KBES) For Ground Water Lowering Method is very suitable for final year project which can give more exposures to student since this project can give very great advantages in other to increase and enhance the development of technology in construction industry. Furthermore this is a starting point for Malaysian since most of the students are not familiar with expert system and subject or project related to it.

1.2.2 Significant of the Project

This project is significant for the assessment of CLIPS software as the expert system tool in determining the best method of ground water lowering process. The data and information will be collected and input in the program and further study on the method of ground water lowering process can be done.

1.3 Objectives and Scope of Study

1.3.1 Objectives

- To familiarize with Knowledge Based Expert System and CLIPS Tool.
- To gather the information and data about Expert System and the domains.
- To know more details about groundwater lowering method in present construction industry nowadays.
- To come out with structured and integrated expert system for selection of groundwater lowering method.

1.3.2 Scope of Study

The study expert system, ground water lowering method and familiarize with clips has to be completed within the time frame given which is approximately 14 weeks of Final Year Project (Part 1). To accomplish the study, research, allocating the resource, work planning, experiment and interview are performed. Generally, in this 14 weeks times, the task that need to be accomplished are searching and gathering the data and all information about expert system, CLIPS and method in ground water lowering process, familiarize with CLIPS and it's programming language and try to program all the input of the domains into CLIPS. Then for second part of this project or for Final Year Project (Part II), the works much more rely and focusing on how to come out with complete, structured and integrated expert system programme that can be run to be used as decision making tool for the user in the process of selecting the best groundwater lowering methods that can suit with characteristic given. Part II also will be focusing on documentation of the project such as final report and final presentation of the project.

1.3.3 The Relevancy of the Project

This project is very much related to the ground water level below the ground surface and the type of the soil materials. Knowledge about the ground water lowering method and information related to it can be improved by doing this project. The objectives of the project are:

i. To come out with structured software that can be used to determine which groundwater lowering method that is suitable for certain characteristic of soil, structure and the cost.

ii. To familiarize with Knowledge Based Expert System that actually gives very great benefits to student especially to learn new things and also help others user to simplified the work.

iii. To use the program for further study in ground water lowering method.

iv. To simplify the works of lowering groundwater in construction industry nowadays.

1.3.4 Feasibility of the Project within the Scope and Time Frame

Since the work is planned properly, this project is to be finished within the given period of time. For Final Year Project (Part I), for the first 7 weeks, the project will focus on preparing the input, data and all information of the domains or ground water lowering methods and also process of preparing the tree and developing the rules for the CLIPS coding. Then for the second 7 weeks, the project will focus on developing the basic programming language or coding that is going to be entered in CLIPS software. For part one of the project, the progress is more focusing on familiarize with knowledge based expert system, get to know the CLIPS software and also gathering data and information as much as possible about the domains. For Final Year Project (Part II), the project will be seriously focusing on the process of entering the rules and command of the CLIPS coding that describe all the information about the domains and need to develop structured and integrated coding. At this stage, the author need to do some correction process from part I and need to learn more difficult coding and to gather more information about the domain in other to key the commands into the project for part II. Second part of this project also mainly focused on documentation of the project such as progress report and final report beside of developed the coding. The aim is to come out with successfully knowledge based expert system for ground water lowering method that can be use by the user especially people working with construction industry in the process of selecting the best groundwater lowering methods for their construction process.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Information about Groundwater Lowering Methods.

2.1.1 Sump Pumping Method

A sump is a pit in which water collects before being bailed or pumped out. Sump pumping is the most basic of dewatering methods. The purposes of this method are:

- ❖ To collect surface water run-off channeled to it by means of collector ditches or channels for discharge to a disposal point or area.
- ❖ To collect and discharge pumped water due to lowering of the ground-water for a shallow excavation, also sump pumping may be required for gravity drainage to toe drains of battered slopes.

Sump pumping can be a very effective and economic method to achieve modest drawdowns in well graded coarse soils such as gravely sands, sandy gravels and coarse gravels or in hard fissured rock. Unfortunately, under some conditions the use of sump pumping can lead to major problems. These problems arise primarily because the flow of water into the excavation can have a destabilizing effect on fine grained soils. This can lead to fine soil particles being washed from the soil with the water. This also known as loss of fines and this things can lead to ground movements and settlements because material is being removed from the soil, giving the potential for the formation and collapse of sub-surface voids. Disposal of the water can also create problems, because if loss of fines occurs the discharge water will have a high sediment load, which can cause environmental problems at the disposal point. Sump pumping has a significant risk of causing loss fines in this soils type:

- ➢ Uniform fine sands
- ➢ Soft non-cohesive silts and soft clays
- ➢ Soft rocks where fissures can erode and enlarge due to high water velocities
- ➢ Rocks where fissures are filled with silt, sand or soft clay, which may be eroded
- ➢ Sandstone with uncemented layers that may be washed out.

At all the times the depth of a sump must be generous amount deeper than the bed of collector drains leading into it and the formation level of the excavation. A sump should be substantially larger than needed to accommodate the pumps. Surface water flowing to the sump is likely to transport fines. These are likely to be abrasive and capable of causing wear and damage to the pumping equipment. A sump of a generous size will allow some settlement of the larger and probably more abrasive fines. Adequate provision should be made for periodic servicing of the pumps and removal of accumulated sediment. The pumps should be suspended so that the bottom of the unit is about 300 mm above the bottom of the sump to allow for some build up of sediment. This does not apply to smaller shallow sumps where the suction hoses only in the sump. The sump should be dug to a greater depth than the main excavation and should be maintained in their original form throughout the construction period, though deepened if necessary as excavation proceeds. This will:

o Allow placement of filter media that may be necessary to minimize loss of ground

o Keep groundwater below excavation level at all stages of the work

o Allow changes to be made in the construction scheme for the main excavation.

Most sumps are formed by excavation *(Figure 1 & 2)* with the sides temporarily supported by sheeting for stability, before the body of the sump is placed. A suitable size placing tube is jetted into the ground to the required depth. A disposable intake strainer and flexible suction hose is lowered into the placing tube in a manner similar to the positioning of a disposable well point and riser pipe. Filter media is placed within the placing tube, around the strainer and riser pipe is connected to a suitable pump.

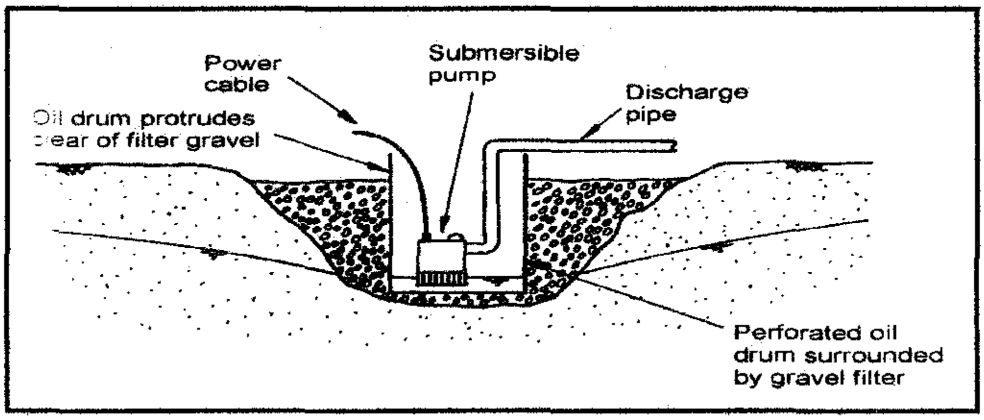

Power cable
Submersible pump
Discharge pipe
Oil drum protrudes clear of filter gravel
Perforated oil drum surrounded by gravel filter

Figure 1: *Small sump formed using perforated oil drum*

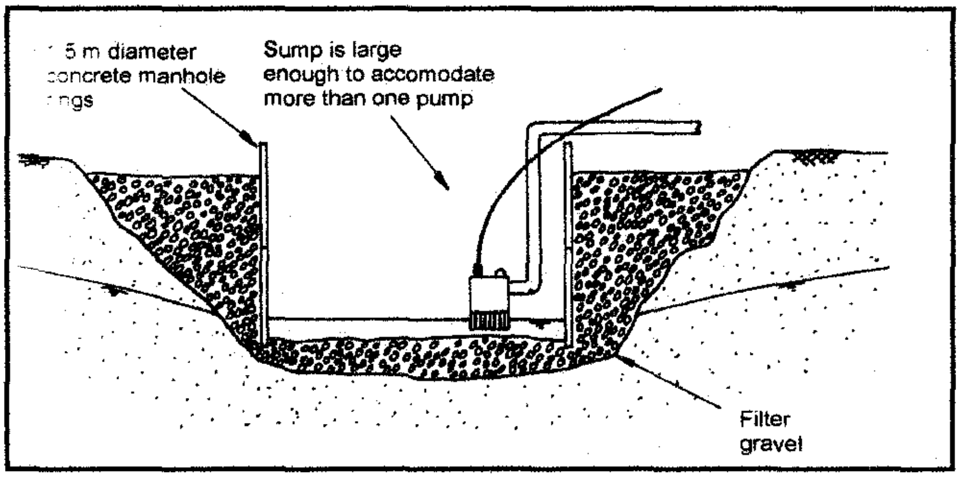


Figure 2: *Large sump formed using concrete manhole rings.*

2.1.2 Wellpoint Systems

A well point system consist essentially of a series of closely spaced small diameter water abstraction points connected, via a manifold, to the suction side of a suitable pump. The well point technique is the pumping system most often used for modest depths excavations, especially for trenching excavations. A well point is a small diameter water abstraction point (the well screen) sometimes referred to as a strainer (so called because of the wire mesh or other strainer of the self-jetting wellpoint) through which the groundwater passes to enter the wellpoint. They are installed into the ground at close centers to form a line alongside *(Figure 3)* or a ring around *(Figure 4)* an excavation.

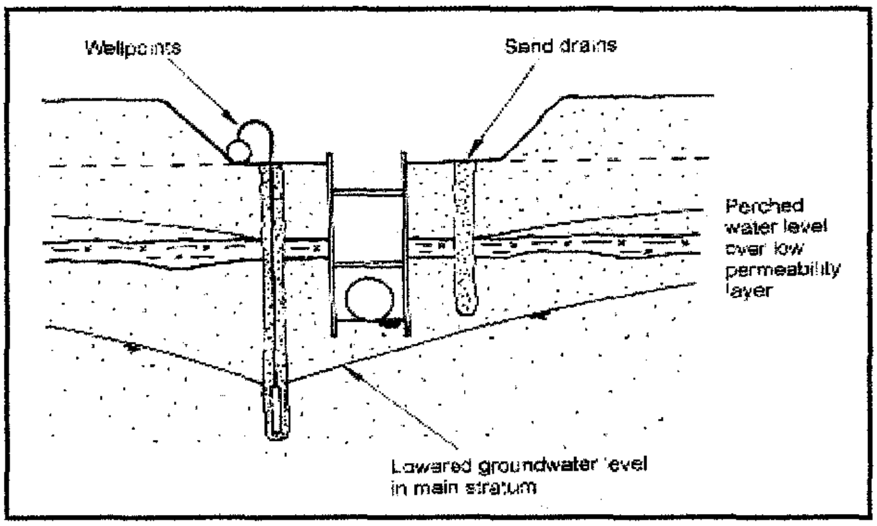

Wellpoints
Sand drains
Perched water level over low permeability layer
Lowered groundwater level in main stratum

Figure 3: *Single-sided wellpoint system*

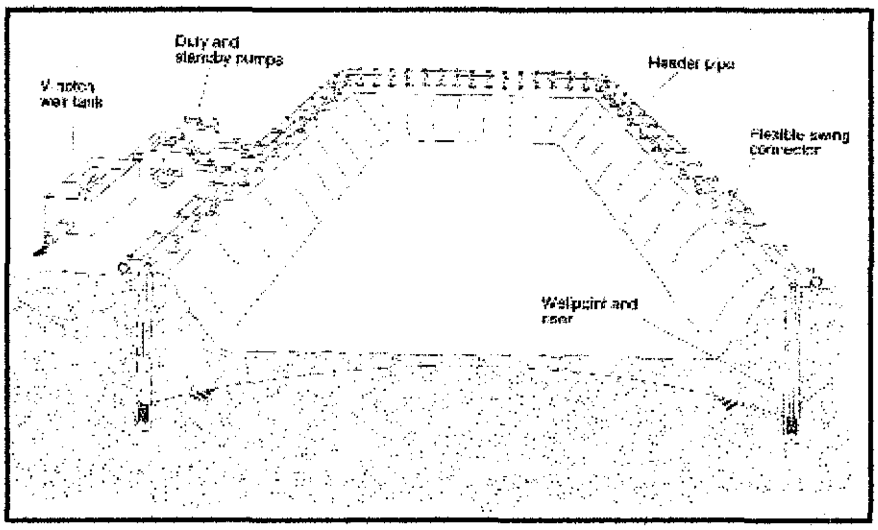


Figure 4: *Wellpoint system components*

There are two types' wellpoints:

- The self-jetting wellpoint *(Figure 5)*

Know as self-jetting since it can be installed without the use of a placing tube. The wellpoint and riser are metal and therefore are rigid, with the wellpoints connected to the bottom of the riser pipe and it a clean water jetting pump. There is a hollow jetting shoe below the wellpoint screen. Near the lower end of the shoe a horizontal pin is located; above the pin is a lightweight loose fitting ball. When the water pressure is applied to install the wellpoint, the ball is displaced downwards to allow the passage of the high pressure water flow but the pin retains the ball within the jetting shoe. When pumping starts the applied vacuum sucks the ball up onto a shaped spherical seating and thereby seals the lower end of the wellpoint, so that water from the surrounding ground can only enter through the screen section. The unperforated riser should extend to near the lower end of the wellpoint screen to minimize the potential for air intake at maximum drawdown.

- The disposable wellpoint *(Figure 6)*

The wellpoint and riser is usually of plastic materials and therefore inert to corrosion. They are installed by means of a placing tube or hole puncher using similar high pressure water jetting techniques for installation as for the self-jetting wellpoint. While many purpose manufactured plastic wellpoints have been marketed for some time, current practice is to adapt low cost thin walled convoluted uPVC perforated land drainage pipe to form disposable wellpoints with woven mesh stocking or coco wrapping. The latter forms a goods filter and in conjunction with the normal sanding in are very effective, even in difficult silty soils. As with the self-jetting wellpoint, the riser (typically made of uPVC ducting) should extend to near the bottom of the screened length. The bottom end of the disposable wellpoint is sealed. Generally the riser pipe is a nominal 6 m long but it can be longer. The disposable wellpoints are not recoverable but some of the plastic riser pipes can sometimes be recovered for future reuse. The disposable wellpoint is very appropriate to use for long duration pumping duty.

There are several techniques of wellpoint installation which are:

- Installation of self-jetting wellpoints *(Figure 7)*
- Installation of disposable wellpoints by placing tube
- Installation using the hole puncher and heavy duty placing tube
- Installation by rotary jet drilling *(Figure 8)*
- Installation through clay strata

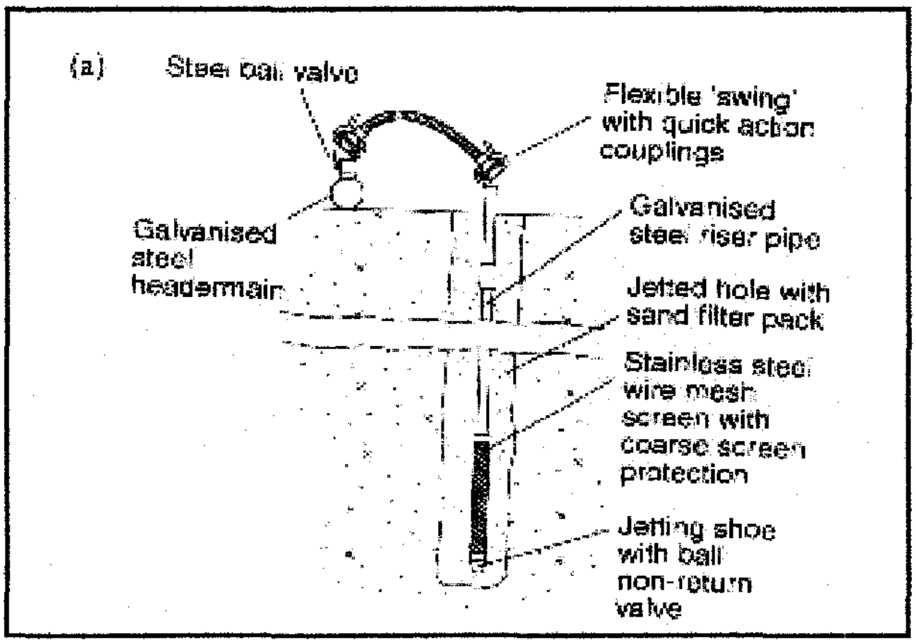

(a)
Steel ball valve
Flexible 'swing' with quick action couplings
Galvanised steel headermain
Galvanised steel riser pipe
Jetted hole with sand filter pack
Stainless steel wire mesh screen with coarse screen protection
Jetting shoe with ball non-return valve

Figure 5: *Self-jetting wellpoint*

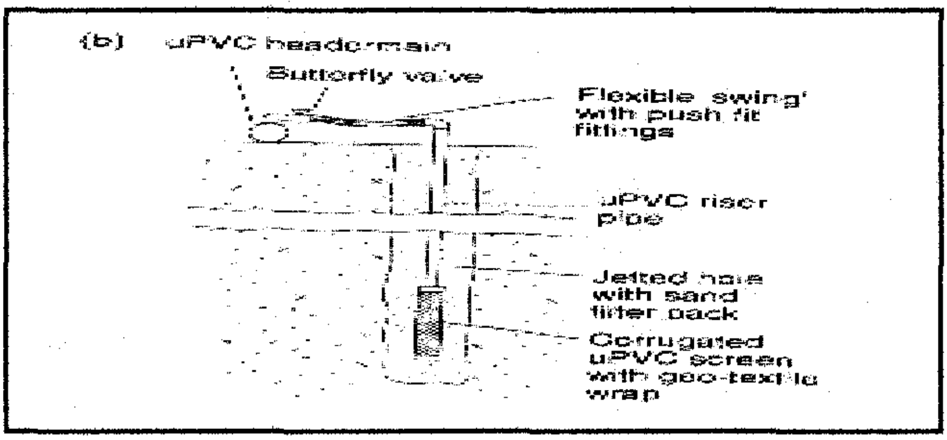

(b) uPVC headermain
Butterfly valve
Flexible swing' with push fit fittings
uPVC riser pipe
Jetted hole with sand filter pack
Corrugated uPVC screen with geo-textile wrap

Figure 6: *Disposable wellpoint*

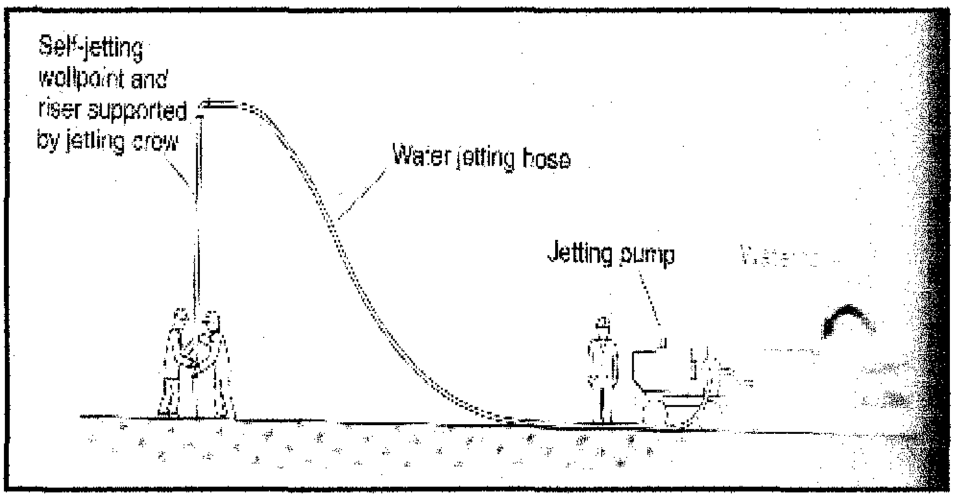


Figure 7: *Installation of self-jetting wellpoint*

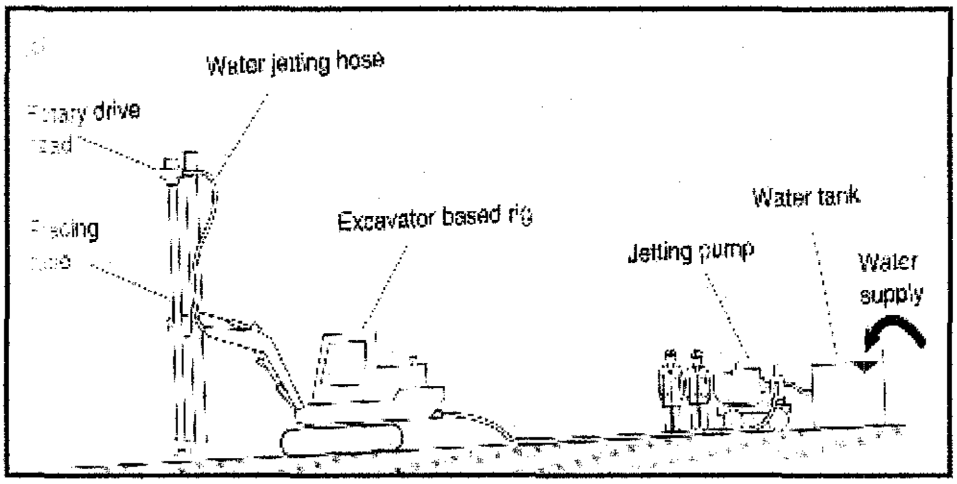


Figure 8: *Installation by rotary jet drilling*

2.1.3 Dewatering System

1) Ejector

The ejector system (known as the eductor or jet-eductor system) is suitable for pore water pressure reduction projects in low permeability soils such as very silty sands, silts or clays with permeable fabric. In such soils the total flow rate will be small and some form of vacuum-assistance to aid drainage is beneficial; the characteristic of ejectors are an ideal match for these requirements. The system involves an array of wells with each well pumped by a jet pump known as ejector. The ejector system works by circulating high pressure water (from a tank and supply pumps at ground level) down riser pipes and through a smaller-diameter nozzle and venture located in the ejector in each well. The water passes through the nozzle at high velocity, thereby creating a zone of low pressure and generating a vacuum draws groundwater into the well through the well screen, where it joins the water passing through the nozzle and is piped back to ground level via a return riser pipe and thence back to the supply pump by circulation. The schematic ejector well system is show in F*igure 9*. Two header mains are needed. A supply main feeds high pressure water to each ejector well and a return main collect the water coming out of the ejector. This large amount of pipe work is needed to allow the recirculation process to continue.

The most obvious advantage of an ejector system is that ejectors will pump both air and water; as a result if the ejectors are installed in a sealed well in low permeability soil a vacuum will be developed in the well. This is one of the main reasons why ejector are suited to use in low permeability soils, where the vacuum is needed to enhance drainage of soils into the wells. Another advantage is that the method is not constrained by the same suction lift limit as a wellpoint system. Drawdowns of 20-30 m below pump level can be achieved with commonly available equipment, and drawdowns is excess of 50 m have been achieved with systems capable of operating at higher supply pressures. These characteristics mean that ejector systems are generally applied in one of two ways:

- Vacuum-assisted pore water pressure control method in low permeability soils.
- As a form of deep wellpoint in soils of moderate permeability as an alternative to a two-stage wellpoint system or a low flow rate deep well system.

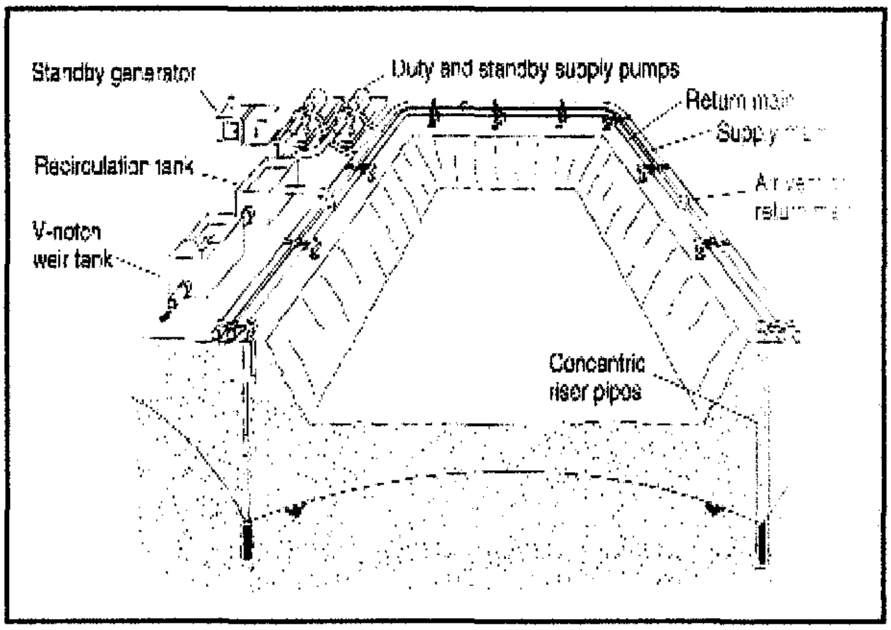


Figure 9: *Ejector System Components*

It is also important to be aware of some of the practical limitations and drawbacks of the ejector system. Perhaps the most significant drawback is the low mechanical (energy) efficiency of ejector systems. In low to moderate permeability soils, where flow rates are small this may not be a major issue, but in higher permeability soils are power consumption and energy costs may be huge in comparison to other methods. This is probably the main reason why the ejector system is rarely used in soils of high permeability. Another potential problem is that, due to the high water velocities through the nozzle, ejector systems may be prone to gradual loss of performance due to nozzle wear or clogging. This can often be mitigated by regular monitoring and maintenance, but it may make long-term operation less straightforward. The ejector design can be categorized into two types, based on arrangement of the supply and return riser pipes:

- Single (or concentric) pipe *(Figure 10)*. This design has the supply and return risers arranged concentrically, with the return riser inside the supply riser. The supply flow passes down the annulus between the pipes, through the ejector and then returns up the central pipe.
- Twin (or dual) pipe *(Figure 11)*. Here the supply and return risers are separate, typically being installed parallel to each other.

The single-pipe ejector has the advantage in that the outer pipe can also be used as the well casing, provided it has sufficient pressure rating; this allows ejectors to be installed in well casings of 50 mm internal diameter. Twin-pipe ejectors need to be accommodated in rather larger well casings. The installation and connection of twin-pipe ejectors involves rather simpler plumbing than for single-pipe designs; this can make the twin-pipe type more suitable for use in localities where skilled labour is scarce and it is desired to keep dewatering equipment as simple as is practicable.

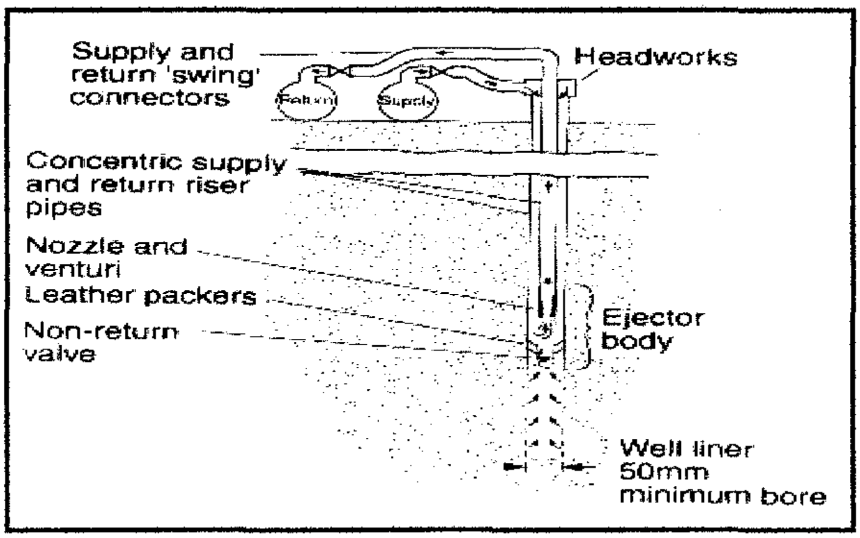

Supply and return 'swing' connectors
Return
Supply
Headworks
Concentric supply and return riser pipes
Nozzle and venturi
Leather packers
Non-return valve
Ejector body
Well liner 50mm minimum bore

Figure 10: *Single-Pipe Ejectors*

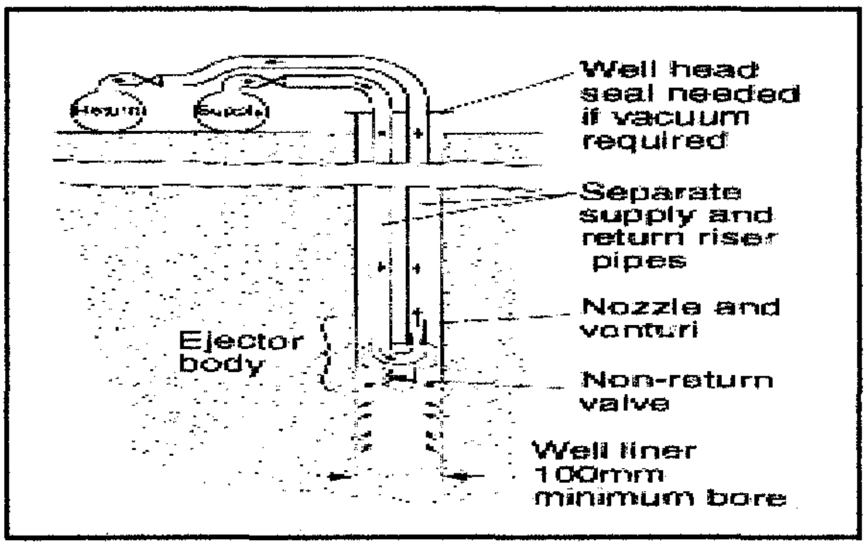

Return
Supply
Well head seal needed if vacuum required
Separate supply and return riser pipes
Nozzle and venturi
Ejector body
Non-return valve
Well liner 100mm minimum bore

Figure 11: *Twin-Pipe Ejectors*

2) Horizontal Wellpoints

This method uses a horizontal flexible perforated pipe, pumped by a suction pump, to effect lowering of water levels. Typically, the perforated pipe is installed by a special land-drain trenching machine *(Figure 12)*. One end of the pipe is unperforated and is brought to the surface and connected to a wellpoint suction pump. A horizontal wellpoint is very efficient hydraulically because it has a very large screen area, and horizontal flow will be plane to the sides of the perforated pipe. This contrasts with flow local to vertical wellpoint systems, where flow lines converge radially to each wellpoint and where the screened area is limited by the short length of the wellpoint screens. The main use of the method is large-scale shallow cross-country pipelines as an alternative to single-stage well pointing, when rapid rates of installation and progression are required. The principal restriction on the use of the method is local availability of the specialist trenching machines to lay the perforated pipe at adequate depth. Trenching machines are capable of installing drains to 6 m depth. In addition to pipeline work, horizontal wellpoints are occasionally used instead of vertical wellpoint to form perimeter dewatering systems around large excavations for dry docks (Anon 1976). If large drawdowns are required, multiple stages of horizontal wellpoints can be installed in a similar way to vertical wellpoint systems.

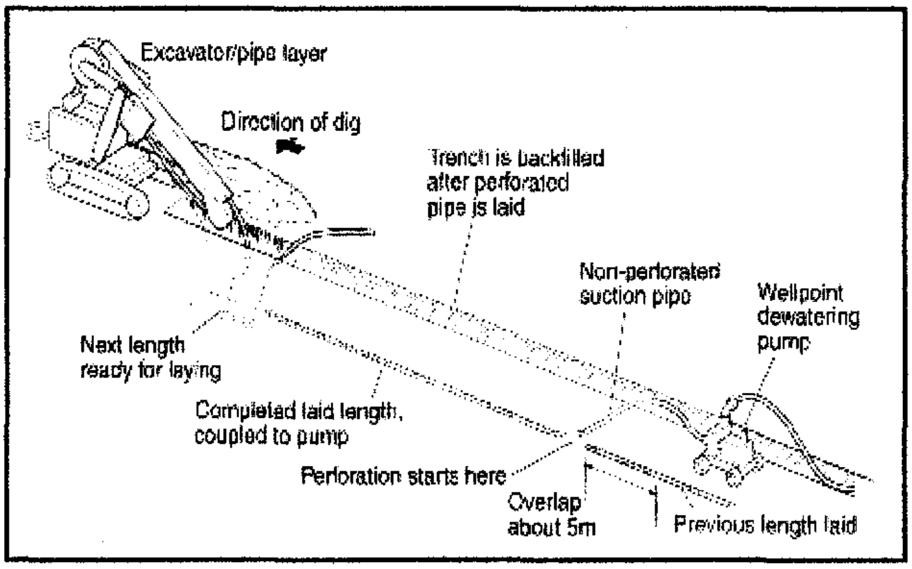

Excavator/pipe layer
Direction of dig
Trench is backfilled after perforated pipe is laid
Non-perforated suction pipe
Wellpoint dewatering pump
Next length ready for laying
Completed laid length, coupled to pump
Perforation starts here
Overlap about 5m
Previous length laid

Figure 12: *Horizontal Wellpoint Installation Using a Land Drain Trenching Machine*

There are principal practical advantages to the use of the horizontal wellpoint *(Figure 13)* method:

- Very rapid rates of installation can be achieved by specialist trenching machines (up to 1000 m per day in favorable conditions); this can be vital when trying to keep ahead of the installation of cross-country pipelines.
- The absence of vertical wellpoints and surface header pipes alongside the trench allows unencumbered access for the pipe lying operations. This has the additional benefits that there are fewer above-ground dewatering installations which might be damaged by the contractor's plant, with the associated risk of interruption of pumping.
- A supply of jetting water is not necessary for installation; and once the drainage pipe has been laid, installation and dismantling is simple and rapid, because only the pumps and discharge pipes are involved, without the need for header pipes.

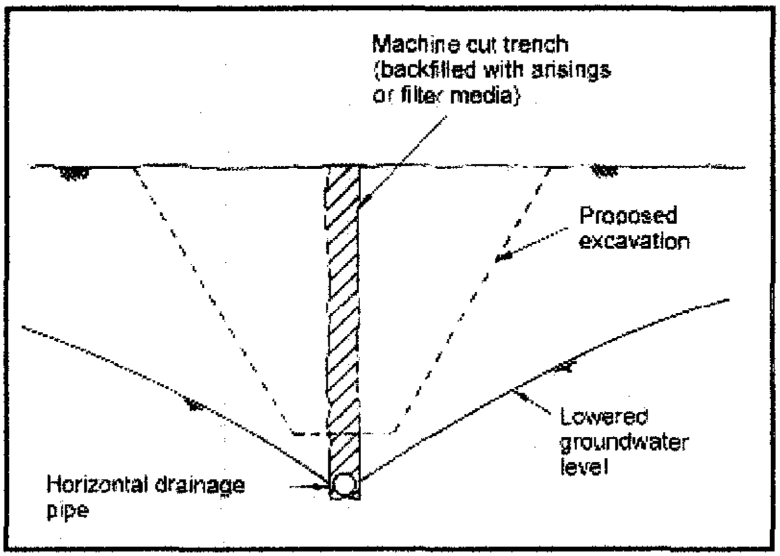

Machine cut trench (backfilled with arisings or filter media)
Proposed excavation
Lowered groundwater level
Horizontal drainage pipe

Figure 13: *Installation of Horizontal Drains for Pipeline Trench*

3) Pressure Relief Wells

When an excavation is made into a low permeability layer above a confined aquifer, there is a risk that pore water pressures in the confined aquifer may cause the base of the excavation to become unstable. The base of the excavation may heave because the weight of soil remaining beneath the excavation is insufficient to balance the uplift force from the aquifer pore water pressure. One way of avoiding this potential instability is to reduce pore water pressures in the aquifer by pumping from an array of deep wells

Such pumped well systems are termed active because pumps are used. The system of pressure relief (or bleed) wells offers an alternative method of reducing pore water pressures in confined aquifers. These systems are passive; this means they are not directly pumped but merely provide preferential pathways for water from the aquifer to bleed away, driven by the existing groundwater heads. The schematic view through a typical relief well system is shown in *Figure 14.* The wells are normally drilled prior to commencement of excavation, or at least before the excavation have progressed below the piezometric level in the aquifer. As excavations continue, the well will begin to overflow, relieving pore water pressures in the aquifer and ensuring stability. The water flowing from the relief wells is typically disposed of by sump pumping.

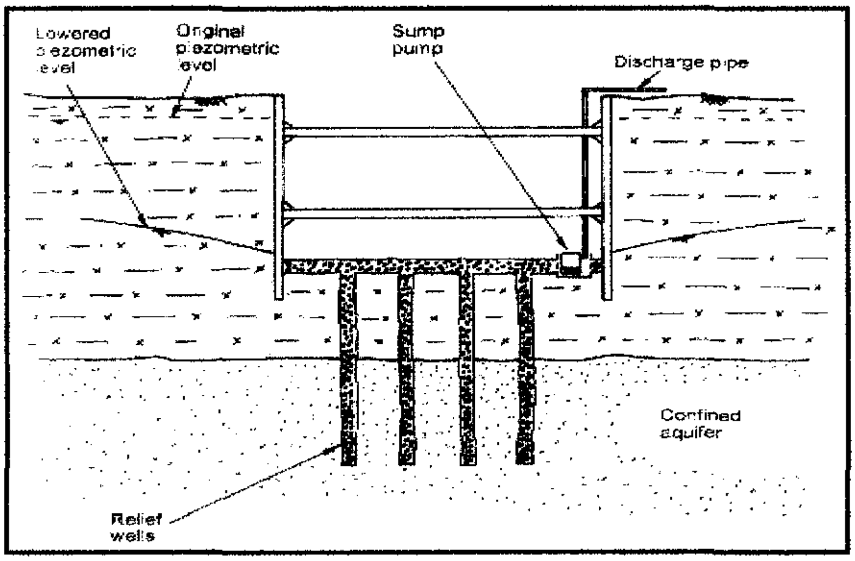


Figure 14: *Relief Well System*

2.1.4 Deep Wells System

A deep well system consists of an array of bored wells pumped by submersible pumps. The wells act in concert – the interaction between the cones of drawdown created by each well result in groundwater lowering over a wide area. Because the technique does not operate on a suction principle, greater drawdowns can be achieved than with a single stage wellpoint system. Each well consists of a bored hole (typically formed by a drilling rig) into which a special well liner is inserted. The liner consists of plastic or steel pipe of which a section is slotted or perforated to form a well screen to allow water to enter. Other sections consist of unperforated pipe (the well casing). Generally, deep well systems are installed in drift deposits and the annulus between the borehole and the well screen/casing is backfilled with filter media of formation stabilizer to form what is known as the filter pack. The wells are generally sited just outside the area of proposed excavation. A deep well system has individual pumps positioned near the bottom of each well; usually the pumps are borehole electro-submersibles. The well screen and casing provides a vertical hole into which a submersible pump attached to its riser pipes can be installed. A typical deep well system *(Figure 15)* consists of several wells acting in concert. Each well creates a cone of depression or drawdown around itself, which in a high permeability aquifer may extend for several hundred meters. The interaction between the cone and the drawdown from each well produces the drawdown required for excavation over a wide area.

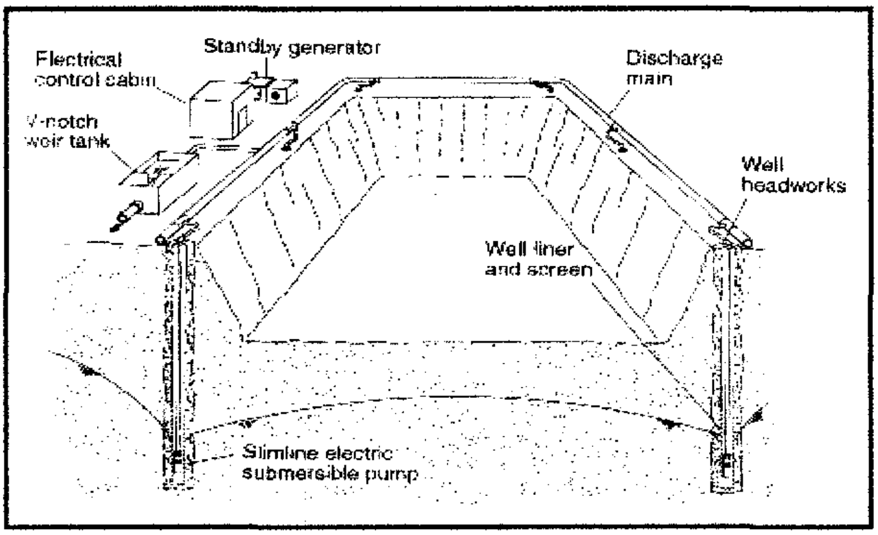


Figure 15: *Deep Well System Components*

The components making up an individual temporary works well are shown in *Figure 16*. Most temporary works requires:

1. The well screen and casing sizes will be in the range of 150 – 300 mm diameter. The well screen and casing are typically plastic, with steel being used only rarely.
2. The drilled borehole sizes will be in the range of 250 – 450 mm diameter.
3. The well depths will be in the range of 10 – 35 meter. Occasionally, wells are drilled to greater depths, especially for shaft or tunnel construction projects.
4. The soils through which the wells are bored are usually drift deposit soils. Occasionally weak rock formations are encountered (such as weak sandstone). The screened length in a rock formation may not need a well screen and filter pack so the required size of bore may be smaller.

The energy costs of operating a deep well installation are likely to be competitive due to the greater efficiency of borehole pumps compared with the total system efficiency of a multi-staged wellpoint installation. The well screens, pumps and other materials are similar to those used for water supply wells. However, since the working life of a temporary works well will almost always significant less than the life of a water supply well, temporary works wells can be constructed by rather cheaper and simpler methods. The initial cost of installing a deep well system is significant. A high standard of expertise in the design and control of installation procedures is required to ensure that the appropriate good practices are implemented throughout and to promote optimum and economic performance.

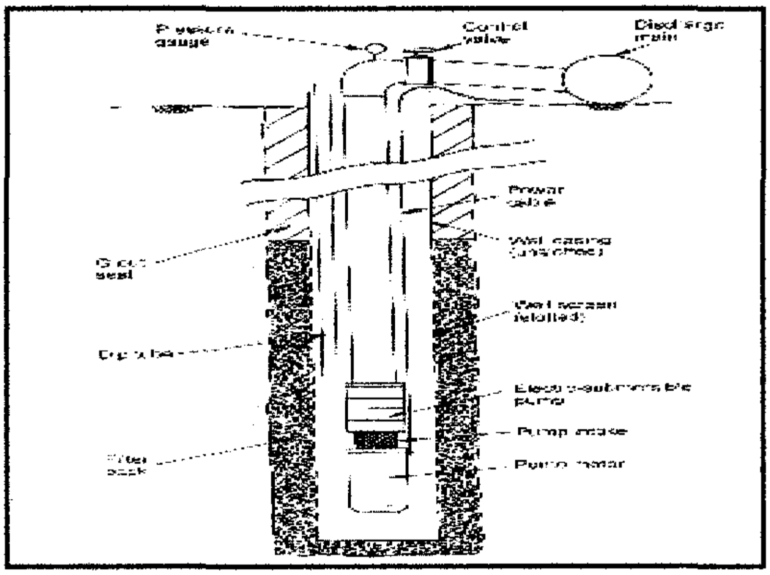


Figure 16: *Schematic Section through a Deep Well.*

Three major factors to be considered when designing and individual temporary works well:

1) Depth of Well and Screen Length

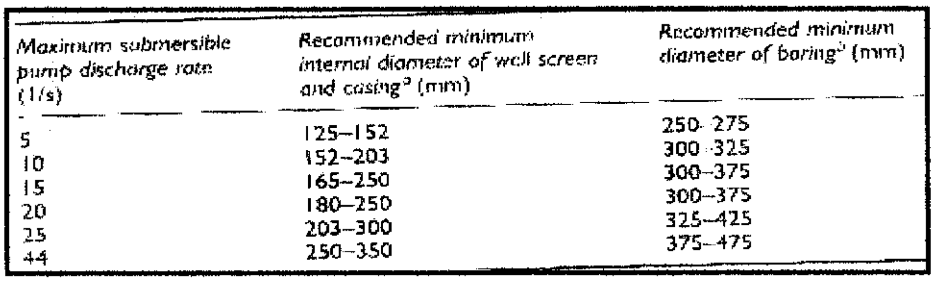
The well must be deep enough to:

- Be able to yield sufficient water so that all the wells in concert can achieve the required flow rate and hence the required drawdown.
- Be of sufficient depth to penetrate the geologic strata in which groundwater pressures are to be lowered (this is especially important if deep confined aquifers are present).

2) Diameter of Well

The diameter of the well will be chosen to ensure that the borehole electro-submersible pump to be used will fit inside the well screen and casing, and that any necessary filter media can be placed around the well screen. This will allow the necessary drilled diameter of borehole to be determined. The starting point for determining the size of the bore is the diameter of the pump to be installed in the well screen.

***Table 1:** Recommended Well Screen and Chasing Diameters*



Maximum submersible pump discharge rate (l/s)	*Recommended minimum internal diameter of well screen and casing[a] (mm)*	*Recommended minimum diameter of boring[b] (mm)*
5	125–152	250–275
10	152–203	300–325
15	165–250	300–375
20	180–250	300–375
25	203–300	325–425
44	250–350	375–475

3) Design of Filter Media and Slot Size

The annulus between the screen and the borehole wall is filled with granular filter media to form a filter pack. The filter media must be selected (based on the particle size distribution of the aquifer material) to meet 2 conditions:

- To be sufficiently coarse so that the filter pack is significant more permeable than the aquifer, to allow water to enter the well freely.
- To be sufficiently fine so that the finer particles are not continually withdrawn from the aquifer.

The selection of any filter media has to be a compromise between these conflicting conditions. Concentrating on condition:

i) Will give a high yield well, but with an increased risk of continuously pulling sand or fines into the well.

ii) Will prevent movement of fine particles but may restrict well yield.

There are four main stages in forming a groundwater lowering well:

1) Drilling of Well Boreholes
   - Cable tool percussion drilling
   - Wash boring and/or jet drilling
   - Rotary drilling: direct circulation
   - Rotary drilling: reverse circulation
2) Installation of materials (screen, casing, gravel, etc)
3) Development of well
4) Installation and operation of pump
   - Installation of borehole electro-submersible pumps
   - Adjustment of electro-submersible pumps
   - Use of deep wells on tidal sites
   - Use of oversized pumps
   - Level control switches
   - Problems due to frequent start up of motor
   - Encrustation and corrosion

2.1.5 Collector Well

Collector well (*Figure 17)* is one of groundwater lowering methods available that can control the groundwater by dewatering techniques. This method is suitable for high permeability sands and gravels. Each collector well is expensive to install, but relatively few wells may produce large flow rates and be able to dewater large areas of site location. Principal advantages of the collector well system:

- Favorable capital cost
- Increased pumping efficiency resulting in lower lifting costs

- Minimal maintenance due to extremely low screen velocities
- Ease of operation due to centralization of all pumping equipment and controls
- Some degree of quality control due to individual operation of each lateral
- Ability to use the entire aquifer due to the horizontal installation of the screens at the bottom of the aquifer
- Safety of the supply

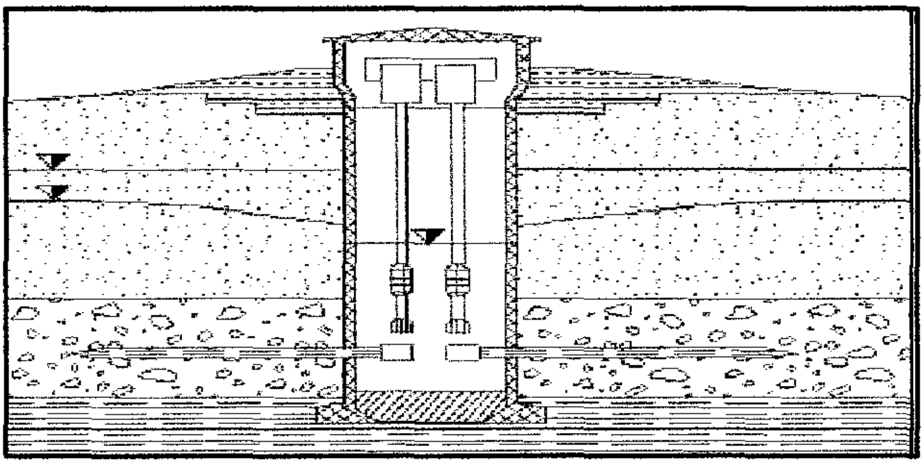


Figure 17: *Collector Well*

The collector well with radial drains presented in *Figure 18* is another possible solution as groundwater lowering method, which enables the extraction of larger quantities of water. It consists of a central shaft of concrete, some 3 or 4 meters diameter, finished off below the water table with a thick concrete plug. From this shaft, perforated radial pipes are jacked horizontally into the aquifer. These pipes may be long, 75 meters for example, in order to increase the area of influence of well.

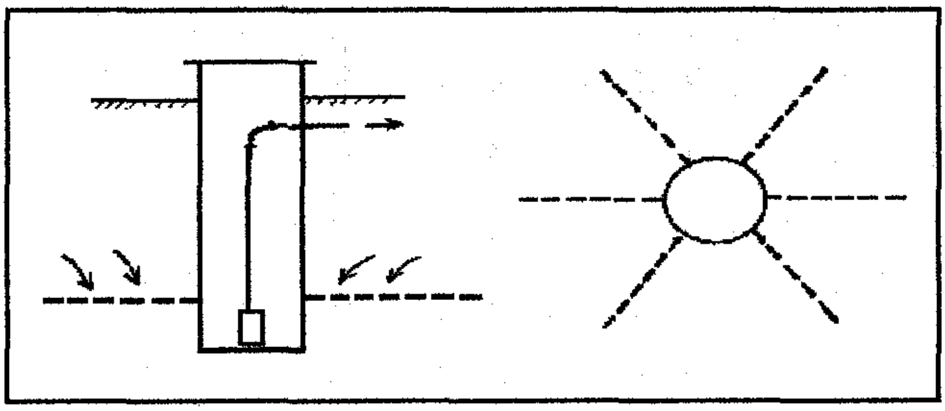


Figure 18: *Collector well with radial drains*

2.1.6 Jet Grouting

Jet Grouting is Ground Modification system used to create in situ cemented geometries of soil (Soilcrete). There are three traditional jet grouting systems as shown on *Figure 19 & 20.* Selection of the most appropriate system is generally a function of the in situ soil, the application, and the physical characteristics of soilcrete required for that application. However, any system can be used for almost any application providing that the right design and operating procedures are used.

- **Single Rod Jet Grouting (Soilcrete S)**

  Grout is pumped through the rod and exits the horizontal nozzles in the monitor with a high velocity, approximately 200 m/sec. This energy causes the erosion of the ground and the placement and mixing of grout in the soil. Single rod jet grouting is generally less effective soils.

- **Double Rod Jet Grouting (Soilcrete D)**

  A two-phase internal rod system is employed for the separate supply of grout and air down to different, concentric nozzles. Grout is used for eroding and mixing with the soil. The air shrouds the grout jet and increases erosion efficiency. The double rod system is more effective in cohesive soils than the single rod system.

- **Triple Rod Jet Grouting (Soilcrete T)**

  Grout, air and water are pumped through different lines to the monitor. High velocity coaxial air and water form the erosion medium. Grout emerges at a lower velocity from separate nozzles below the erosion jet. This somewhat separates the erosion process from the grouting process and yields a higher quality soilcrete. Triple-rod jet grouting is the most effective system for cohesive soils.

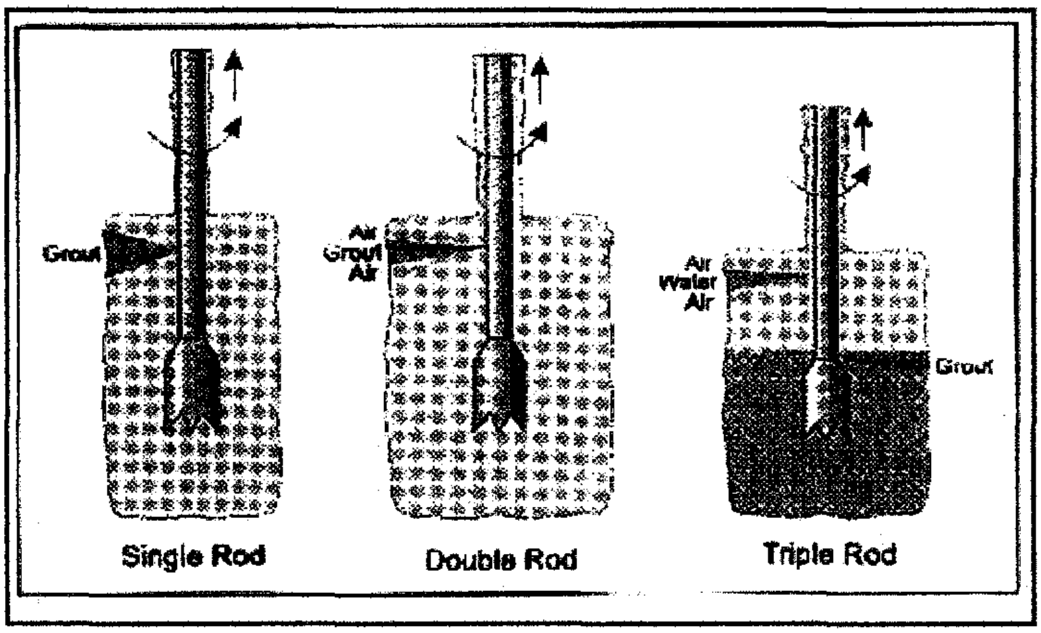


Figure 19: *Three traditional jet grouting systems*

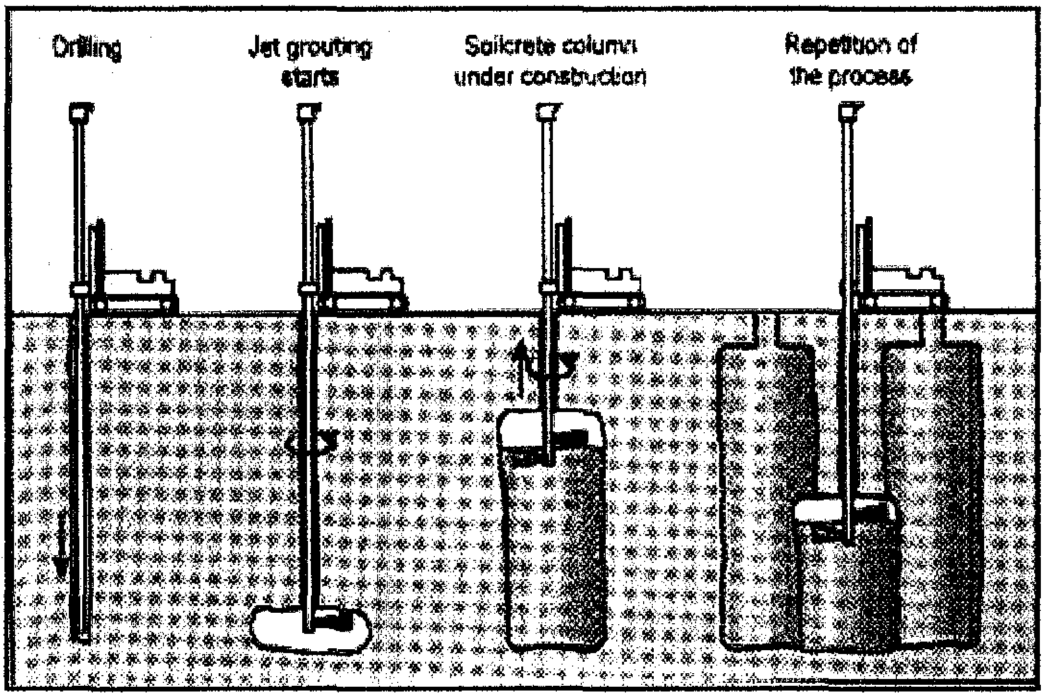
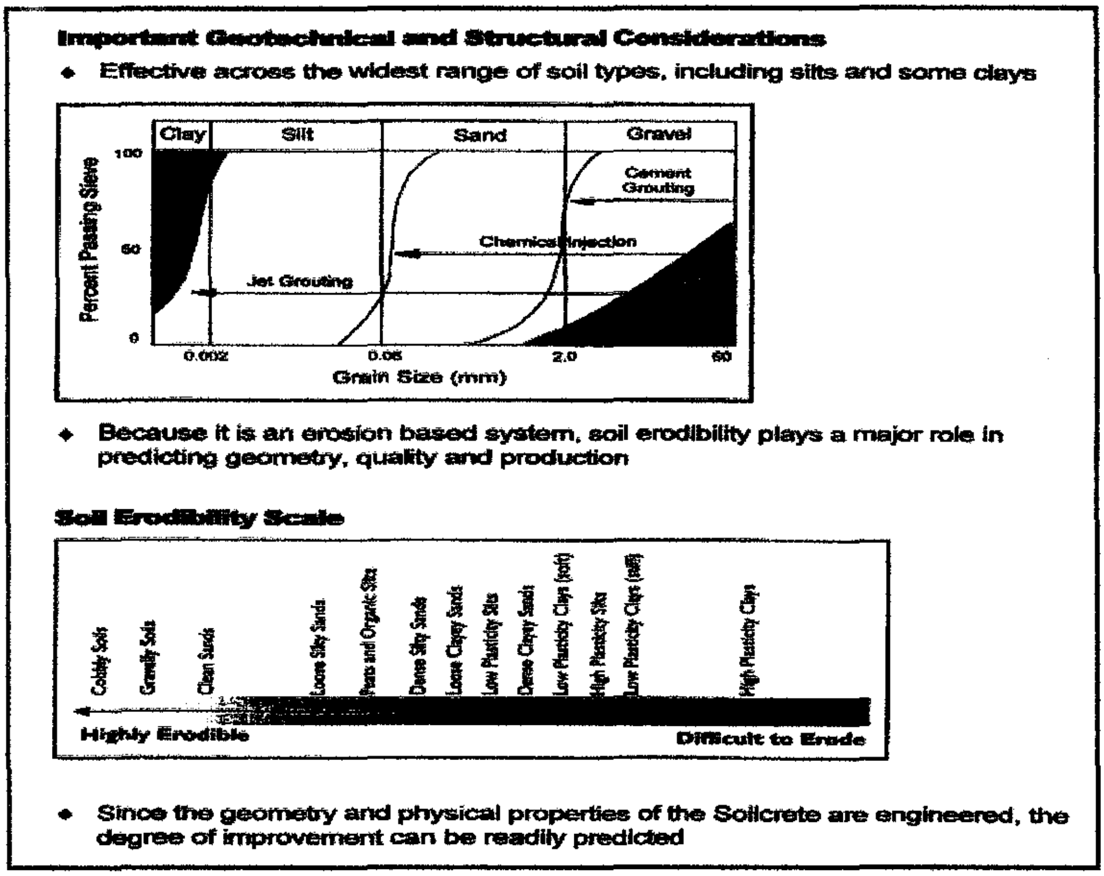

Drilling
Jet grouting starts
Soilcrete column under construction
Repetition of the process

Figure 20: *Jet grouting process*



Important Geotechnical and Structural Considerations

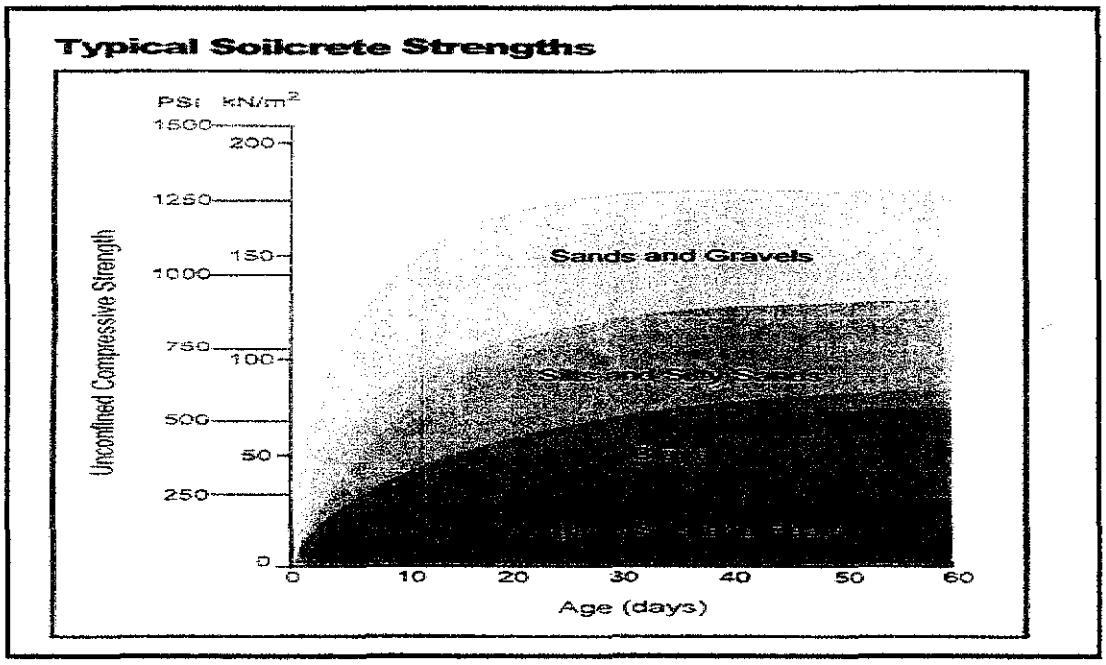
- Effective across the widest range of soil types, including silts and some clays

- Because it is an erosion based system, soil erodibility plays a major role in predicting geometry, quality and production

Soil Erodibility Scale

- Since the geometry and physical properties of the Soilcrete are engineered, the degree of improvement can be readily predicted

Figure 21: *The data about soil for Jet grouting*



Typical Soilcrete Strengths

Figure 22: *Typical Soilcrete strength*

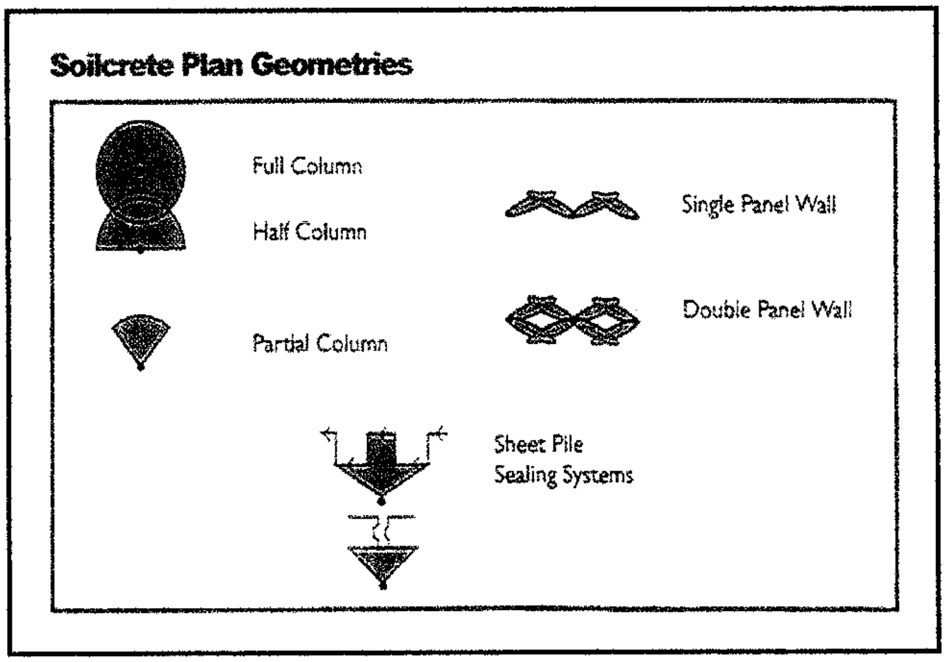


Figure 23: *Soilcrete plan geometries*

Jet Grouting Application

- Offers an alternative to conventional grouting, chemical grouting, deep slurry trenching, proprietary underpinning systems, or the use of compressed air or freezing in tunneling, etc.
- Jet grouting should be considered in any situation requiring control of underground fluids, or excavation of unstable soil, whether water-bearing or otherwise.

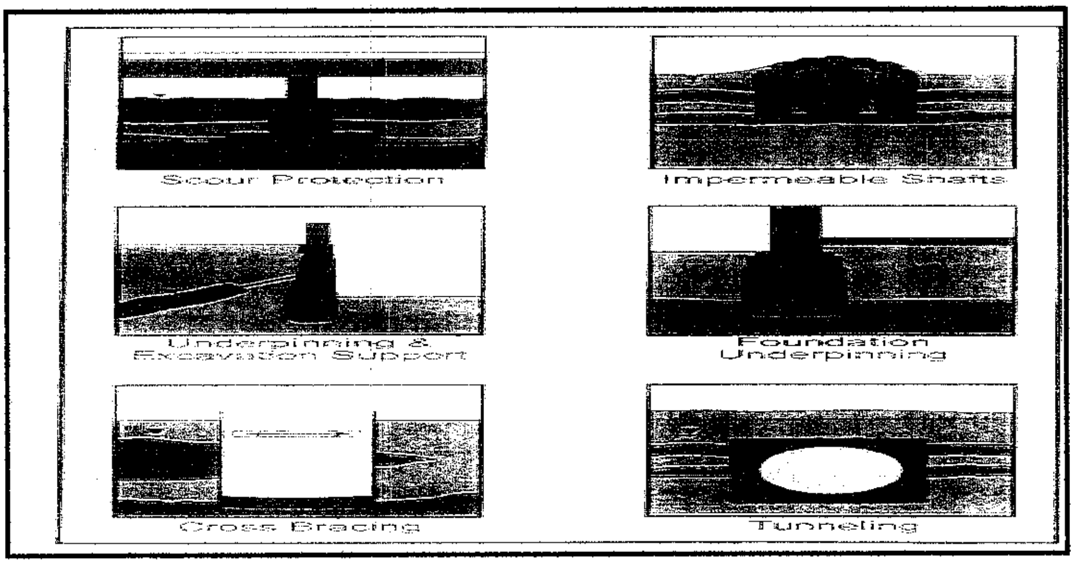
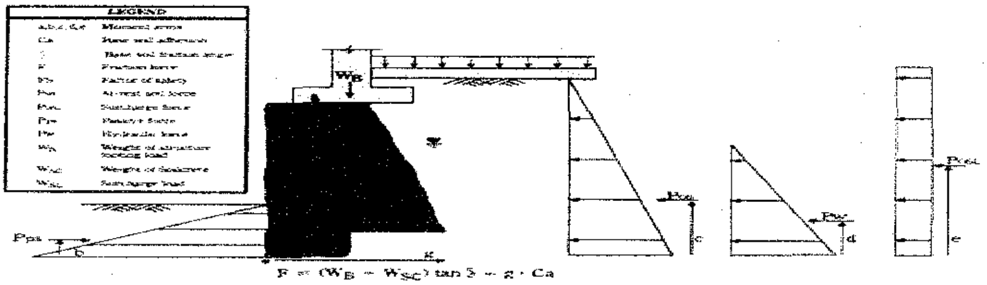


Figure 24: *Application of Jet grouting*

Design Considerations for Underpinning

- Bearing capacity of the system
- Retaining system evaluation for lateral earth pressures and surcharge loads
- Settlement review
- Strength adequacy of the system



$$F = (W_B + W_{SC}) \tan \delta + g \cdot Ca$$

$$\text{FS overturning*} = \frac{(W_B + W_{SC})\,a + Pps \cdot b}{(Pos \cdot c) + (Pw \cdot d) + (Posc \cdot e)} \geq 1.5 \qquad \text{FS sliding} = \frac{Pps + F}{Pos + Pw + Posc} \geq 1.5$$

Design Considerations for Excavation Support

- What depth is necessary and what shear strength and geometry of Soilcrete will resist the surcharge, soil and water pressure imposed after excavation?
- Are soil anchors or internal bracing necessary?

Design Considerations for Groundwater Control

- What integrity is possible from interconnected Soilcrete elements and how much water can be tolerated through the Soilcrete barrier?

Figure 25: *Design consideration*

Advantages of Jet Grouting

- Nearly all soil types groutable
- Specific in situ replacement possible
- Designable strength and permeability
- Treatment to specific subsurface locations
- Only inert components
- No harmful vibrations
- Limited working space required
- Any cross-section of soilcrete possible
- Maintenance free
- Safest method of construction
- Ability to work around buried active utilities
- The most effective means of direct underpinning of structures and utilities
- Much faster than alternative methods

2.2 CLIPS Commands

CLIPS expert systems may be executed in three ways: interactively using a simple, text-oriented, command prompt interface; interactively using a window/menu/mouse interface on certain machines; or as embedded expert systems in which the user provides a main program and controls execution of the expert system. The generic CLIPS interface is a simple, interactive, text-oriented, command prompt interface for high portability. The standard usage is to create or edit a knowledge base using any standard text editor, save the knowledge base as one or more text files, exit the editor and execute CLIPS, then load the knowledge base into CLIPS. The interface provides commands for viewing the current state of the system, tracing execution, adding or removing information, and clearing CLIPS. The primary method for interacting with CLIPS in a non-embedded environment is through the CLIPS **command prompt** (or **top level**). When the "CLIPS>" prompt is printed, a command may be entered for evaluation. Commands may be function calls, constructs, global variables, or constants. If a function call is entered, that function is evaluated and its return value is printed. Function calls in CLIPS use a prefix notation—the operands to a function always appear after the function name. Entering a construct definition at the CLIPS prompt creates a new construct of the appropriate type. Entering a global variable causes the value of the global variable to be printed. Entering a constant at the top level causes the constant to be printed (which is not very useful). For example:

```
CLIPS> (+ 3 4)
7
CLIPS> (defglobal ?*x* = 3)
CLIPS> ?*x*
3
CLIPS> red
red
CLIPS>
```

CLIPS provide eight primitive data types for representing information. These types are **float, integer, symbol, string, external-address, fact-address, instance-name** and **instance-address**. Numeric information can be represented using floats and integers. Symbolic information can be represented using symbols and strings. A **number** consists *only* of digits (0-9), a decimal point (.), a sign (+ or -), and, optionally, an (e) for exponential notation with its corresponding sign. A number is either stored as a float or an integer. Any number consisting of an optional sign followed by only digits is stored as an **integer** (represented internally by CLIPS as a C long integer). All other numbers are stored as **floats** (represented internally by CLIPS as a C double-precision float). The number of significant digits will depend on the machine implementation. Round off errors also may occur, again depending on the machine implementation.

- Some examples of integers are
  237 15 +12 -32
- Some examples of floats are
  237e3 15.09 +12.0 -32.3e-7
- Specifically, integers use the following format:
  <integer> ::= [+ | -] <digit>+
  <digit> ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
- Floating point numbers use the following format:
  <float> ::= <integer> <exponent> |
  <integer> . [exponent]
  <unsigned integer> [exponent]
  <integer> . <unsigned integer> [exponent]
  <unsigned-integer> ::= <digit>+
  <exponent> ::= e | E <integer>

A **symbol** in CLIPS is any sequence of characters that starts with any printable ASCII character and is followed by zero or more printable ASCII characters. Simple examples of symbols are:

foo, Hello, B76-HI, bad_value, 127A, 456-93-039, @+=-%, 2each

A **string** is a set of characters that starts with a double quote (") and is followed by zero or more printable characters. A string ends with double quotes. Double quotes may be embedded within a string by placing a backslash (\) in front of the character. A backslash may be embedded by placing two consecutive backslash characters in the string. Some examples are:

"foo" , "a and b", "1 number" , "a\"quote"

An **external-address** is the address of an external data structure returned by a function (written in a language such as C or Ada) that has been integrated with CLIPS. This data type can only be created by calling a function (i.e. it is not possible to specify an external-address by typing the value). Within CLIPS, the printed representation of an external-address is:

<Pointer-XXXXXX>, where XXXXXX is the external-address.

A **fact** is a list of atomic values that are either referenced positional (ordered facts) or by name (non-ordered or template facts). Facts are referred to by index or address. The printed format of a **fact-address** is:

<Fact-XXX>, where XXX is the fact-index.

An **instance** is an **object** that is an instantiation or specific example of a **class.** Objects in CLIPS are defined to be floats, integers, symbols, strings, multi-field values, external-addresses, fact-addresses or instances of a user-defined class. A user-defined class is created using the **def class** construct. An instance of a user-defined class is created with the **make-instance** function, and such an instance can be referred to uniquely by address. An **instance-name** is formed by enclosing a symbol within left and right brackets. Thus, pure symbols may not be surrounded by brackets.

[pump-1] [foo] [+++] [123-890]

An **instance-address** can only be obtained by binding the return value of a function called **instance-address** or by binding a variable to an instance matching an object pattern on the LHS of a rule representation of an instance-address is:

<Instance-XXX>, where XXX is the name of the instance.

A placeholder that has a value (one of the primitive data types) is referred to as a **field.** The primitive data types are referred to as **single-field values.** A **constant** is a non-varying single field value directly expressed as a series of characters (which means that external-addresses, fact-addresses and instance-addresses cannot be expressed as constants because they can only be obtained through function calls and variable bindings). A **multi-field value** is a sequence of zero or more single field values. When displayed by CLIPS, multi-field values are enclosed in parentheses. Collectively, single and multi-field values are referred to as **values**. Some examples of multi-field values are:

(a) (1 bar foo) () (x 3.0 "red" 567)

2.3 Making Good Rules

The author also has learnt about how to make a good rule of CLIPS for expert system. A rule is similar to an IF THEN statement in a procedural language like Ada, C, or Pascal. An IF THEN rule can be expressed in a mixture natural language and computer language as follows:

IF certain conditions are true

THEN execute the following actions

Another term for the above statement is pseudocode, which literally means false code. While pseudocode cannot be directly executed by the computer, it serves as very useful guide to writing executable code. Pseudocode is also helpful in documenting rules. A translation of rules from natural language to CLIPS is not very difficult if keep this IF THEN analogy in mind. The example of pseudocode for a rule as below:

IF the animal is a duck, THEN the sound made is quack

The following is a fact and a rule named duck which is the pseudocode above expressed in CLIPS syntax. The name of the rule follows immediately after the keyboard defrule. Although can enter a rule on a single line, it's customary to put different parts on separate lines to aid readability and editing.

```
CLIPS > (clear)
CLIPS > (unwatch facts)
CLIPS > (assert (animal-is duck))
<Fact-0>
CLIPS> (defrule duck
        (animal-is duck)
=>
  (assert (sound-is quack)))
```

The same rule is shown following with comments added to match the parts of the rule. Also shown is the optional **rule-header** comment in quotes. There can be only one rule-header comment and it must be placed after the rule name and before the first **pattern**. The pattern can be matched against a **pattern entity** which mean is either a fact or an instance of a user-defined class. CLIPS tries to match the pattern of the rule against a pattern entity. White space consisting of spaces, tabs and carriage returns may be used to separate the elements of a rule to improve readability. Others comments begin with a semicolon and continue until carriage return key is pressed to terminate the line. Comments are ignored by CLIPS.

```
(defrule duck "Here comes the quack"     ; Rule header
    (animal – is duck)                   ; Pattern
=>                                       ; THEN arrow
    (assert (sound-is quack)))           ; Action
```

Each of rule patterns and **actions** must be surrounded by parentheses. An action is actually a function which typically has no return value, but performs some useful action such as an (assert) or (retract). For example an action might be (assert (duck)). Here the function name is "assert" and its argument is "duck". Notice, that don't want any return value such as a number. Instead, want the fact (duck) to be asserted. A **function** in CLIPS is a piece of executable code identified by a specific name, which returns a useful value or performs a useful side-effect, such as (printout).

A rule often has multiple patterns and actions. The number of patterns and actions do not have to be equal, which is why different indices, N and M, were chosen for the rule patterns and actions. Zero or more patterns may be written after the rule header. Each pattern consists of one or more fields. In the duck rule, the pattern is (animal-is duck), where the fields are "animal-is" and "duck". CLIPS attempts to match the patterns of rules against facts in the fact-list. If all the patterns of a rule match facts, the rule is **activated** and put on the **agenda**. The agenda is a collection of **activations** which are those rules which match pattern entities. Zero or more activations may be on the agenda. The symbol "=>" that follows the patterns in a rule is called an **arrow**. The arrow represents the beginning of the THEN part of an IF-THEN rule (and may be read as "implies"). The last part of a rule is the list of zero or more actions that will be executed when the rule **fires**. In our example, the one action is to assert the fact (sound-is quack). The term fires means that CLIPS has selected a certain rule for execution from the agenda.

A program will cease execution when no activations are on the agenda. When multiple activations are on the agenda, CLIPS automatically determines which activation is appropriate to fire. CLIPS order the activations on the agenda in terms of increasing priority or **salience**. The part of the rule before the arrow is called the left-hand side **(LHS)** and the part of the rule after the arrow is called the right-hand side (**RHS**). If enter a (**reset**) command, CLIPS memory is cleared and the special fact (initial-fact) is always put into the fact-list with fact-identifier "f-0". If no patterns are specified, the pattern (initial-fact) is used for the LHS.

CHAPTER 3
METHODOLOGY / PROJECT WORK

3.1 Procedure Identification

Phase of research and development are identified to ensure smooth running of the project. Basically, the methodology divided into 4 main stages:

3.1.1 Selection of Project Topic

This stage is crucial to ensure that the topic is feasible in term of scope and time frame. Preliminary research is conducted for each scope of work and analyzed.

3.1.2 Project Planning

All defined scope and work is outlined along specific time frame to keep track with on-going and planned activities. It is vital to keep updates with the outlined activities and its time frame to minimize behind schedule activities. Project planning can be referred at *appendix 1* for FYP part 1 and *appendix 2* for FYP part II.

3.1.3 Literature Study

Most information is gathered from journal, internet and library and through discussion with supervisor and colleagues. Available research by individual on related topics serves as a useful reference for basic of understanding.

3.1.4 Project Work

Working on the project base on the schedule and planning. For this project, the first stage (Part I) is to prepare the data to be input in the program, learning about the software used and continue with the further study and analysis during the second stage. Part II of this project will focused on the process of key in more coding and commands into the project to come out with more structured and integrated project that is ready to be used as selection tool for selecting the best groundwater lowering methods for construction industry nowadays. Project work flow chart for Part I and Part II can be referred at the *appendix 3*.

3.2 Tools & Equipment Used

- Window base PC

  The basic window software like Microsoft Word, Excel and Power Point is being used throughout the project. This is in order to prepare the reports for the project, to make calculation using the spreadsheet and to prepare the presentation slide.

- CLIPS Software

  The software that is going to be used to develop the knowledge based expert system for ground water lowering method.

- CLIPS Reference Manual expert system project

  The manual that gives a few tutorial and the examples of the coding for CLIPS software.

CHAPTER 4
RESULTS & DISCUSSION

4.1 Findings

4.1.1 Develop the Tree

There are several methods that can be done to develop and represent the knowledge about the domains, which are tree method, table, object, fuzzy chart and so on. Tree chart is a powerful chart making tool that produces excellent clear Descendant and Ancestor charts, which can include photographs. It is possible to combine several different charts together to make a chart that covers all ancestors. The only real limit is the imagination of a person in creating the chart. In making this tree chart, first of all, is need to ask 5 W (what, when, where, why and who) and 1 H (how) about the domain which is ground water lowering method to gather more data and have wider information about the domain. For developing the tree, author need identify to whether want to structure deep tree or wide tree. For representing the knowledge using wide tree *(Figure 26),* just need to identify or do specification for only one or two stage but if using deep tree *(Figure 27)* we have to specify more stages of specification of the domains up to 4 or 5 stages.

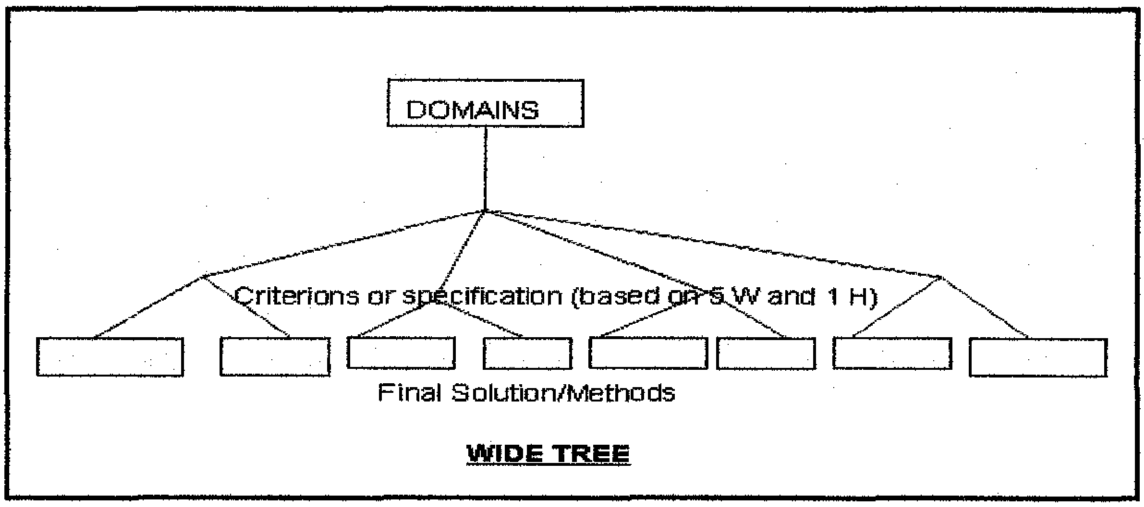


Figure 26: *Structure for Wide Tree*

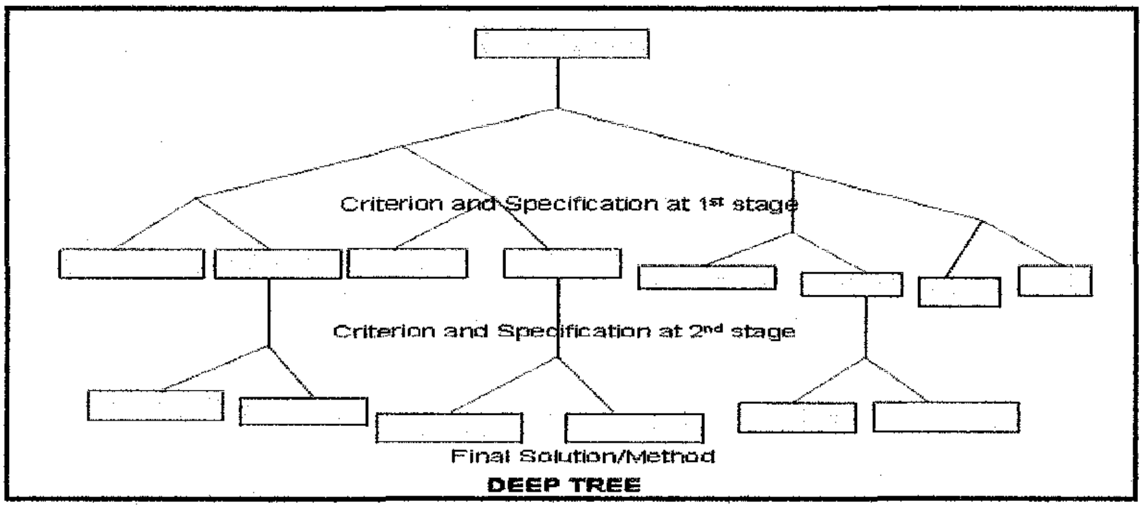

Criterion and Specification at 1st stage
Criterion and Specification at 2nd stage
Final Solution/Method
DEEP TREE

Figure 27: *Structure for Deep Tree*

In representing the knowledge about ground water lowering method, the author had already specified the criterions and characteristic of all the methods available. The specification for 1st stage is based on the site conditions which are consisting of layering of the soil below the ground whether shallow layer or deep layer. Another thing is about environment of the site condition whether urban or rural area and the third specification are about the access to the site location. For this specification, the author had specified it due to efficiency of the ground water lowering methods and system and also the power of it based on site location and it condition, whether wet or dry condition. Then, another specification is the availability of the equipments or the system due to time and location of the site. For examples, at the rural area; which method is the best to be used? Cost of the system/method/equipment also important to be specified. For certain type of soil condition, certain type of structures need to specified the best method that can be applied so that it would not increase the cost of operating and maintaining the equipment. Last specification is about loading condition whether vertical loading, horizontal loading or both vertical and horizontal loading that will be applied at certain type of site location. The example of main tree chart for this ground water lowering method can be referred at the *appendix 5*.

4.1.2 Develop Sub Tree/Sub System

For this sub tree of groundwater lowering method, it can be divided into several characteristic or called sub system which are the selection of method depend on type of soil, type of excavation, the economical value and also features and function of each lowering method. This sub tree system or structure is used to get to know more details and for better understanding about the domains since the main tree structure is look more complicated and difficult to understand. This is because main tree structure was combined with all the sub system or criterion to be considered in selection method process. The example of sub tree system for this ground water lowering method can be referred at the *appendix 6* for type of excavation, *appendix 7* for type of soil and at *appendix 8* for cost characterization.

4.1.3 Represent Knowledge into Circle

Another way of representing the knowledge or info of the domains is by putting in into the circle diagram. This diagram functions like tree chart but it gives clearer and understandable for the user to understand about the domains and the characteristic of each method. It also can make user easily understand about how the domains has been divided into several module according to the specification such as types of soil, type of excavation, type of installation, and cost of each method whether cheap, expensive or based on materials or excavation depth. One specification will represent one module. So this diagram helps the author easily to put the commands from each module into CLIPS. There are 2 types of diagram that the author already did, which are the main circle diagram that represent the whole characteristic or specification of the domains and the sub circle diagrams that already specific to only one characteristic of the domains. The diagram can be referred at *appendix 9* for main circle diagram and for sub diagram representing type of excavation at *appendix 10.* The sub diagram representing type of soil can be referred at *appendix 11* and for sub diagram of cost at *appendix 12.* In creating this sub circle diagram, the author just focused on the 3 main characteristic only as stated above.

4.1.4 Develop the Rules for Each Ground Water Lowering Method

Among early stages of producing Knowledge Based Expert System is to develop the rules of groundwater lowering system so that it can be easily used to develop and create the command or coding for CLIPS software. Usually process of developing the rules of the domains (groundwater lowering methods) is done after process of gathering all the information and data about the domains and also after making the trees structure and sub system for the domains. The rules are going to be entered in the CLIPS software in form of CLIPS programming language or in other names as the command for that software. The rules is important so that can get overview what type of commands that are going to be use whether yes/no question or direct the user to choose the option provided by the author. For this project (knowledge based expert system for groundwater lowering system) the author had decided to develop the commands that allow the user to choose the option provided (criterion for groundwater lowering methods) by selecting number for the initial stage. Then the author will let the user to use yes or no commands for further stages of more specific stages after they are already selected criterion that they wanted in initial stage. That means the author will combine both command which are yes or no commands and choose option commands. For initial stages of making this expert system, the author had decided to develop the rule which is actually based on type of excavation for groundwater lowering system such as open excavation, shallow excavation, deep excavation, tunnel and shaft excavation and so on. The rules also will depend on the economical values of the system and also the types of soil at site location.

For second stages which is during final year project part 2 (FYP Part II), the aims for this project is to add more criterion and rules of choosing the groundwater lowering method available so that this expert system will become more structured and more integrated system that can be applied in construction industries. Process of developing the rules is actually very much depending on the tree structure and also sub-system. The example of the rules:

Initial stages

- What are the type of excavation
  1. Open excavation

2. Shallow excavation
3. Deep excavation
4. Tunnel & Shaft (Tunnel only or shaft only or both)
5. Others (Diaphragm walls, surface water, confined aquifer)

- What types of soil at site location
  1. Most soil
  2. Most soil + weak rocks
  3. Silts & sands
  4. Silts, sands & gravels
  5. Sand gravel, fine & silty sands
  6. Clean coarse soils
  7. Gravels, coarse sands & fissured rocks
- The cost of the methods
  1. Relatively expensive
  2. Relatively cheap
  3. Depend on materials used
  4. Depend on the depth of excavation
- What type of installation
  1. Permanent installation
  2. Temporary installation

Second stages

- The site location contained very low permeability soils (yes or no)
- The system is for controlling surface water (yes or no)
- The system is for controlling under groundwater (yes or no)
- Do you consider about the cost of the system (yes or no)
- Is the site is easy to be accessed (yes or no)
- The type of excavation is for tunnel only (yes or no)
- The type of excavation is for shaft only (yes or no)
- The type of excavation is for both tunnel and shaft (yes or no)

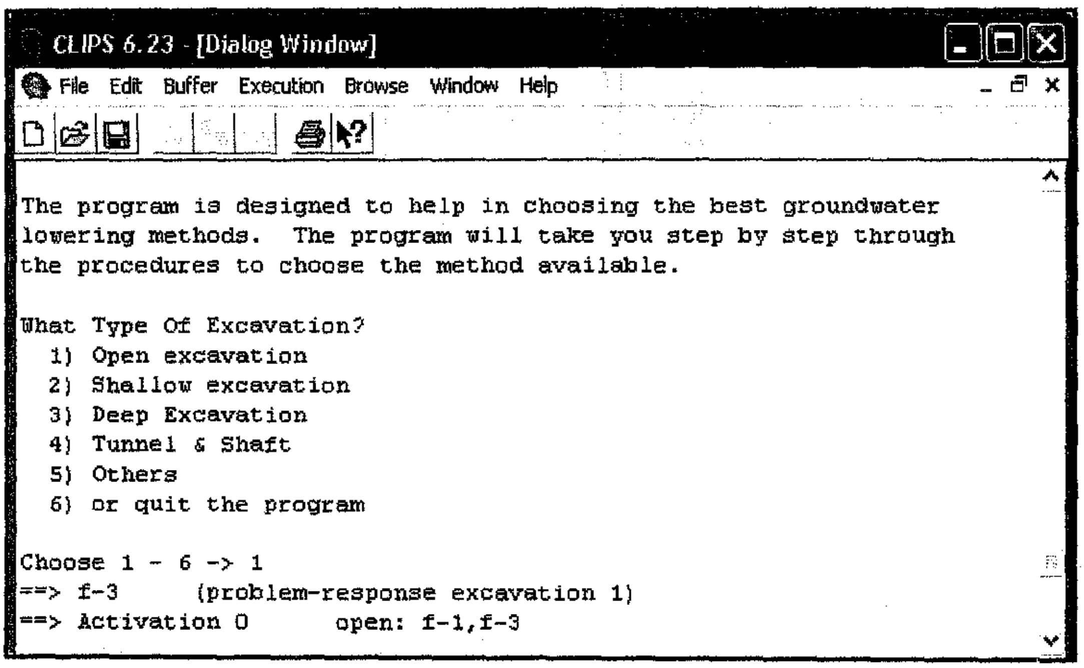
4.1.5 Develop the Command of Ground Water Lowering Method for CLIPS

The author had already developed basic command for this expert system project for the domains of groundwater lowering system during FYP part 1. But some problems had occur which is the program cannot be run because there are some error with the command which is the author do not know how to put the command when there is a case to select either one several type of excavation such as excavation associating with tunnel and shaft. Actually there are some groundwater lowering methods that only function for tunnel on and there are a few that function only for shaft only and there are also a few methods with can function for both shaft and tunnel. So it a bit hard to create the command that the user can select only one type of mentioned above. Then the correction process and development process of coding has been done during FYP part II to come out with more structured and integrated program that can be run for the process of selecting groundwater lowering methods.

4.1.6 System of the Project

As discussed before, the purpose of this project is to come out with system/programme that can be used by user to select the best method for lower the groundwater in the construction site. The developing of the system is by using CLIPS as an expert tool. The coding will be created in this software and the CLIPS will be run to give direction to the user in progress to select the best method. Before the system can gives the result, a user need to answer a few questions related to the characteristic of the groundwater lowering method that they want or suit with site condition and all the characteristics are already specified by the programmer within CLIPS. Actually in developing the coding of the system, the author already divides the characteristic of groundwater lowering methods into 5 modules which are first module is depend on Open Excavation, second is Shallow Excavation, third is Deep Excavation, fourth is Tunnel & Shaft and the last modules is for other type of excavation such as Diaphragm Wall, Surface Water, Confined Aquifer and so on. In developing the coding, the author needs to go through modules by modules so that all methods are in the system and to avoid confusing during developing the coding. How the system works as below:

1) The system will ask the first question and the user need to select the answer and key into it.


CLIPS 6.23 - [Dialog Window]
File Edit Buffer Execution Browse Window Help

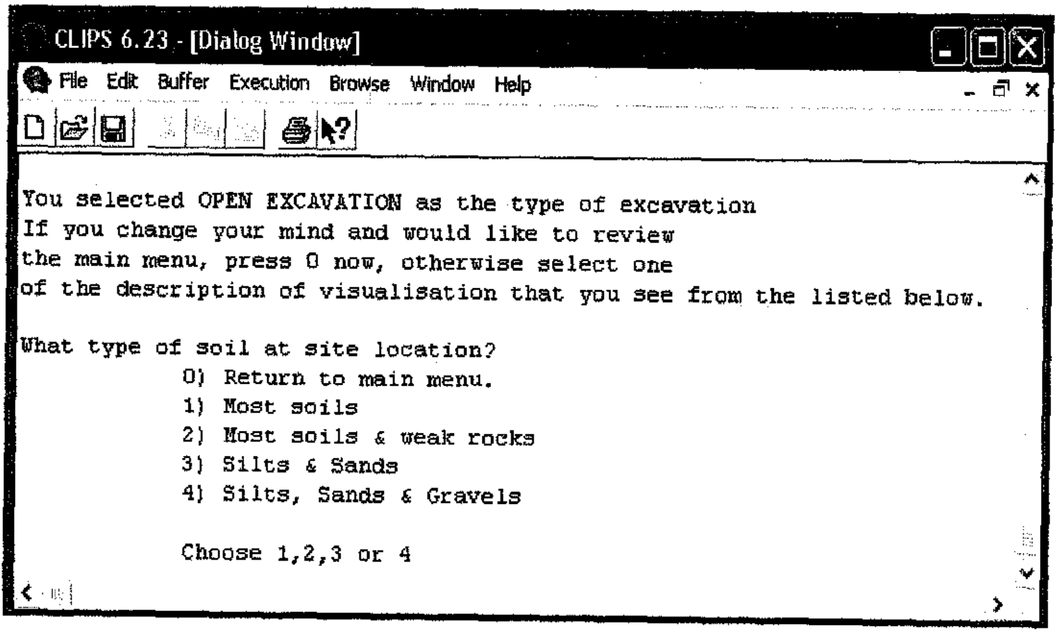
```
The program is designed to help in choosing the best groundwater
lowering methods.  The program will take you step by step through
the procedures to choose the method available.

What Type Of Excavation?
  1) Open excavation
  2) Shallow excavation
  3) Deep Excavation
  4) Tunnel & Shaft
  5) Others
  6) or quit the program

Choose 1 - 6 -> 1
==> f-3     (problem-response excavation 1)
==> Activation 0      open: f-1,f-3
```

Figure 28: *Example of system for First Question and Answer*

2) Then the system will ask second question that relate or chain from the first question.


CLIPS 6.23 - [Dialog Window]
File Edit Buffer Execution Browse Window Help

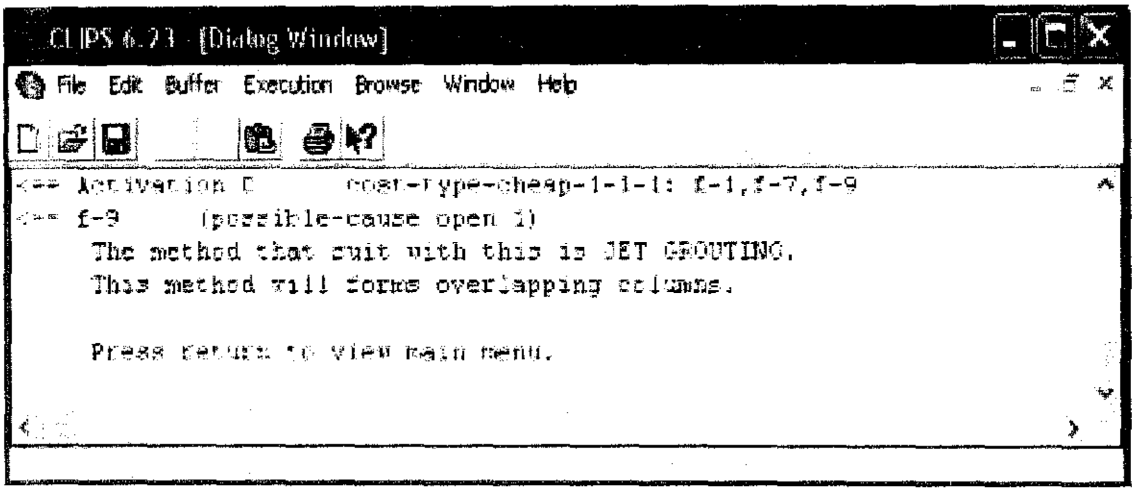
```
You selected OPEN EXCAVATION as the type of excavation
If you change your mind and would like to review
the main menu, press 0 now, otherwise select one
of the description of visualisation that you see from the listed below.

What type of soil at site location?
            0) Return to main menu.
            1) Most soils
            2) Most soils & weak rocks
            3) Silts & Sands
            4) Silts, Sands & Gravels

            Choose 1,2,3 or 4
```

Figure 29: *Example of system for Second Question that is related to the First Answer*

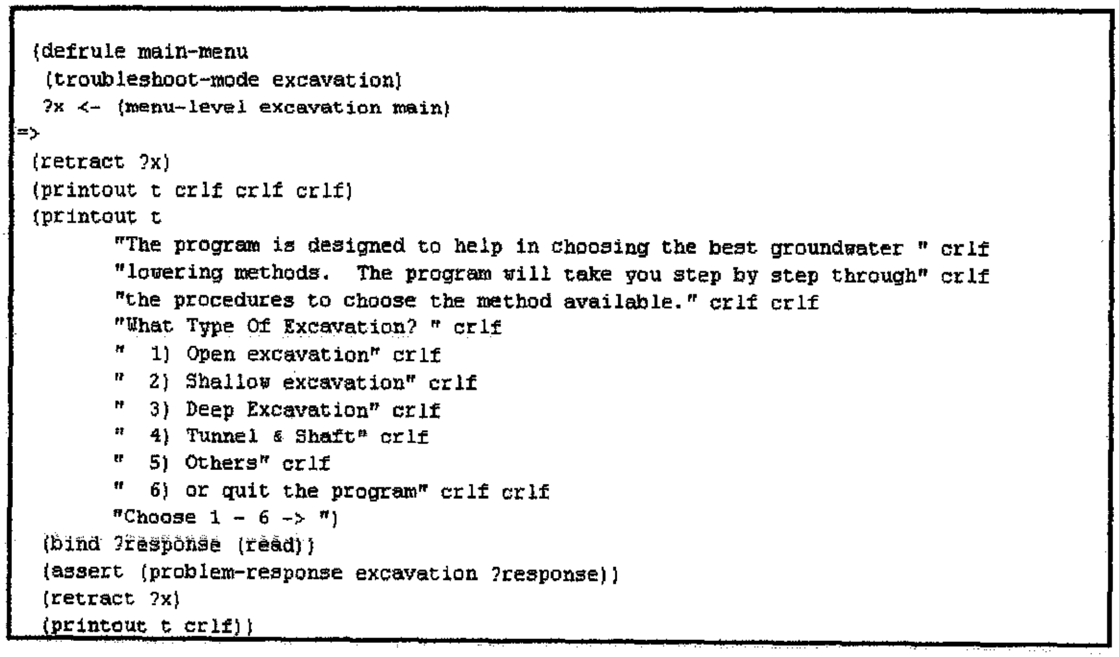
3) The programme will continue asking a few more questions until it specify which best method that suit with characteristic that the user are already select.
4) Then finally, the programme will give the user the best method that suit with characteristic that the user wants.


CLIPS 6.23 - [Dialog Window]
File Edit Buffer Execution Browse Window Help

```
<== Activation 0      cost-type-cheap-1-1-1: f-1,f-7,f-9
<== f-9      (possible-cause open 1)
    The method that suit with this is JET GROUTING.
    This method will forms overlapping columns.

    Press return to view main menu.
```

Figure 30: *Example of the Decision*



```
 (defrule main-menu
  (troubleshoot-mode excavation)
  ?x <- (menu-level excavation main)
=>
 (retract ?x)
 (printout t crlf crlf crlf)
 (printout t
       "The program is designed to help in choosing the best groundwater " crlf
       "lowering methods.  The program will take you step by step through" crlf
       "the procedures to choose the method available." crlf crlf
       "What Type Of Excavation? " crlf
       "  1) Open excavation" crlf
       "  2) Shallow excavation" crlf
       "  3) Deep Excavation" crlf
       "  4) Tunnel & Shaft" crlf
       "  5) Others" crlf
       "  6) or quit the program" crlf crlf
       "Choose 1 - 6 -> ")
  (bind ?response (read))
  (assert (problem-response excavation ?response))
  (retract ?x)
  (printout t crlf))
```

Figure 31: *Example of the Coding*

The overall coding of the project can be referred at *appendix 13.*

4.2 Discussion

The gathering on the specific domain is actually focused on the main method for lowering ground water level. The main method are sump pumping, wellpoint systems, deep well system and other dewatering systems such as ejectors, horizontal wellpoint pressure relief wells and many more. The collecting process of the information for specific method of ground water lowering system is actually can gives more clearer understanding on how the system work, the process to set up the apparatus, the cost of the method and the effect of the system to the surroundings.

Tree and circle diagram actually help a lot in developing this project because this diagrams shown clearer information about the domains and help the author easily on how to develop the rules and commands and also help in constructing the coding of the project.

About the coding of the program, actually all the examples given from CLIPS package are the simple command of the system. So the author need to study and do research more to familiarize with more difficult commands of CLIPS software so that can be used for this project to come out with one structured and integrated expert system of groundwater lowering method. Since this CLIPS software is very new to the author, so there are a lot of problems faced to understand the coding and to construct the rules and command of the project. Furthermore there is no specialist in this CLIPS software that the author can refer to beside supervisor Dr. Indra because this type project or expert system is not famous yet in Malaysia.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

Knowledge Based Expert System is very great project and need to be exposed to the student in every field of study since this project can give very great benefits such as simplify the selection of any works method and it help people from other area to understand the area of certain workers. For example people in engineering field can also use expert system to understand any tool or method use in medicine field. It actually gives students great benefits for them to learn how to develop their own knowledge based expert system. Furthermore this expert system need to be started familiarize with Malaysian since this system already being using by developed country. This is important so that we can compete with them in term of technology use so decrease the gap in technology.

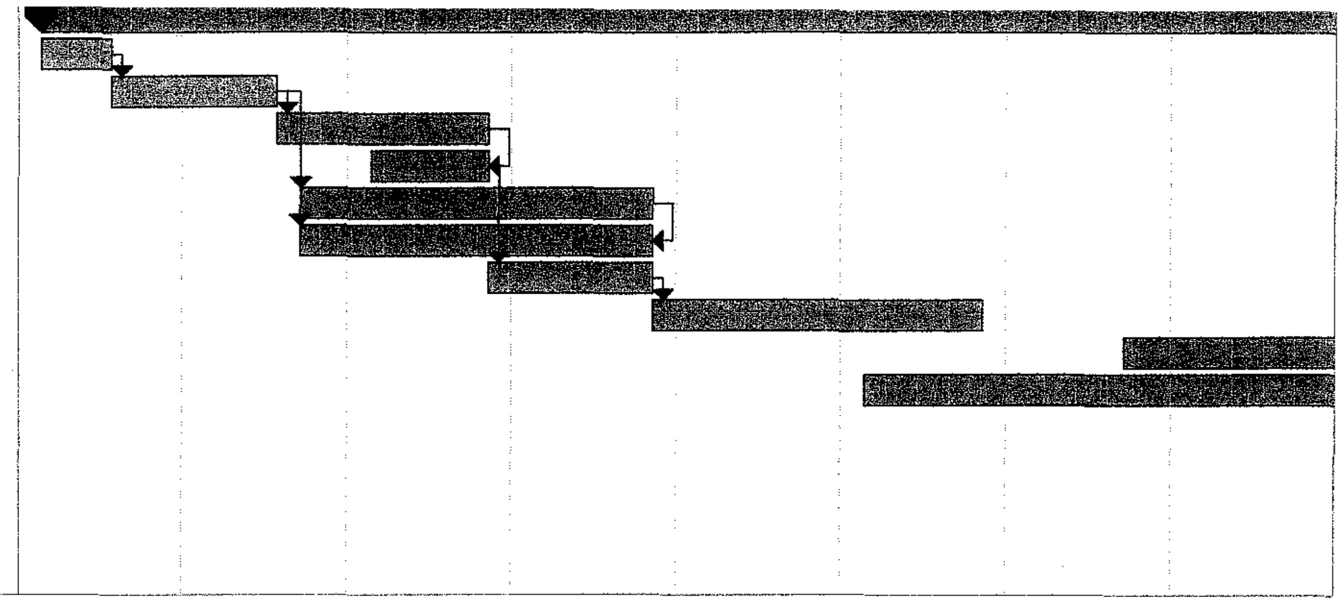
5.2 Recommendation

Since this project give very good advantages in order to increase to development in construction technology, so it need to be exposed to all student widely so that we can compete with development country that already use this expert system quiet long time ago. This project can be exposed to all field of study not only construction field but also can be applied to medicine, law and many more so that they can come out with their own expert system that can be used by all people.

In developing this project, first things that need to do is to collect and gather as much information about the domains as possible because this information is very important to develop the coding, rules and command of the project. Beside, it also helps a lot in understanding the whole project and easily to create the coding of the project. For better understanding of the project and domains, the developers need to come out with structured tree diagram and as well as circle diagrams. These 2 diagrams can give clearer information about the domains and how to divide the domains into the module for the CLIPS coding.

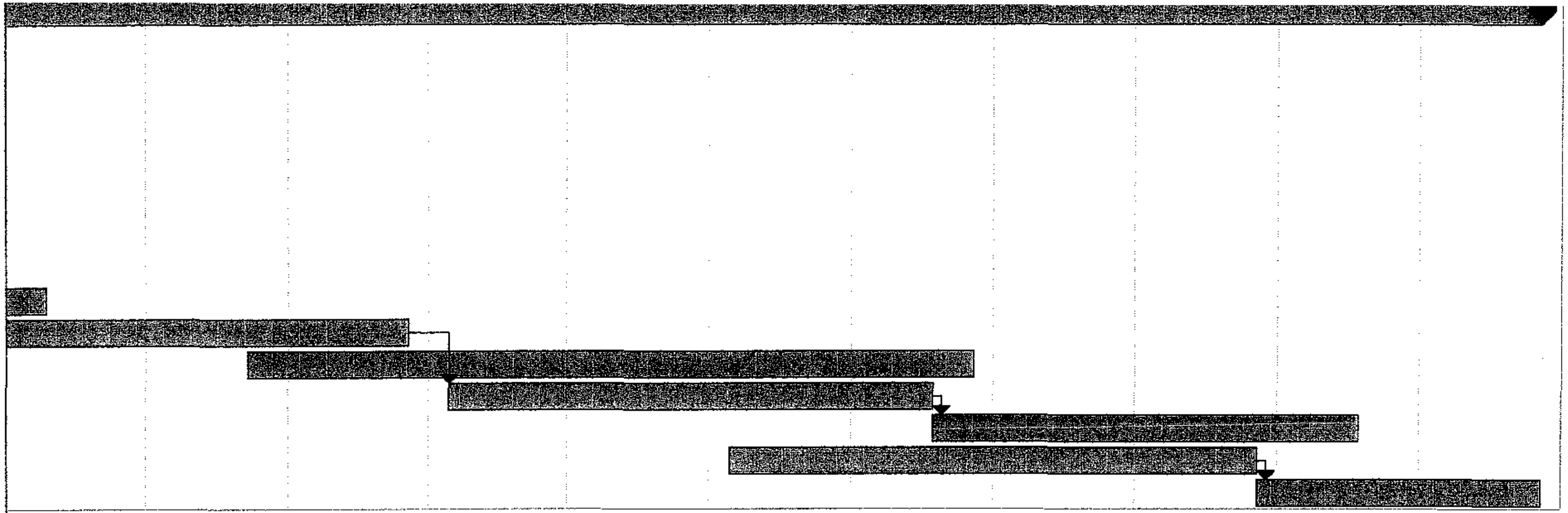
APPENDICES

1	**Final Year Project Part 1**
2	Introduction To FYP 1
3	Topic Confirmation Process
4	Research On The Topic
5	Preliminary Report
6	Gathering Data About Expert System
7	Gathering Data About Domains
8	Knowledge Representation Using Tree
9	Develop The Rules
10	Progress Report
11	Familiarize With Clips And Coding
12	Interim Report
13	Programme Data of The Domain Into Clips
14	Develop And Adjustment Of The Project
15	Final Report
16	FYP 1Presentation Preparation



Project: Gantt Chart FYP 1
Date: Mon 6/4/07

Task	▭	Milestone	◆	External Tasks	▭
Split	⋯⋯⋯	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩



Project: Gantt Chart FYP 1
Date: Mon 6/4/07

Task	▭	Milestone	◆	External Tasks	▭
Split	┅┅┅	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩

APPENDIX: 2

PROJECT MILESTONE FYP II

No	Details/Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Search new info about the domains	▨	▨	▨	▨	▨	▨	▨								
2	Review comment from FYP 1 Presentation	▨	▨	▨												
3	Study CLIPS coding & examples			▨	▨	▨	▨	▨								
4	Develop more structured rules/commands				▨	▨	▨	▨	▨	▨						
5	Preparation/submission Progress Report 1				▨	▨	▨									
6	Develop/do correction process of CLIPS coding					▨	▨	▨	▨	▨	▨	▨	▨			
7	Preparation/submission Progress Report 2.							▨	▨	▨	▨					
8	Final correction of coding/comeout with complete programme										▨	▨				
9	Prepare for the exhibition for EDX.					▨	▨	▨	▨	▨	▨	▨				
10	Poster exhibition (EDX).								▨	▨	▨	▨				
11	Prepare for oral presentation.										▨	▨				
12	Oral Presentation.												▨			
13	Submit 1st Draft of interim to the supervisor.											▨	▨			
14	Make a correction.													▨		
15	Submission of Dissertation Final Draft.														▨	
16	Submission of Project Dissertation.														▨	▨

APPENDIX : 3

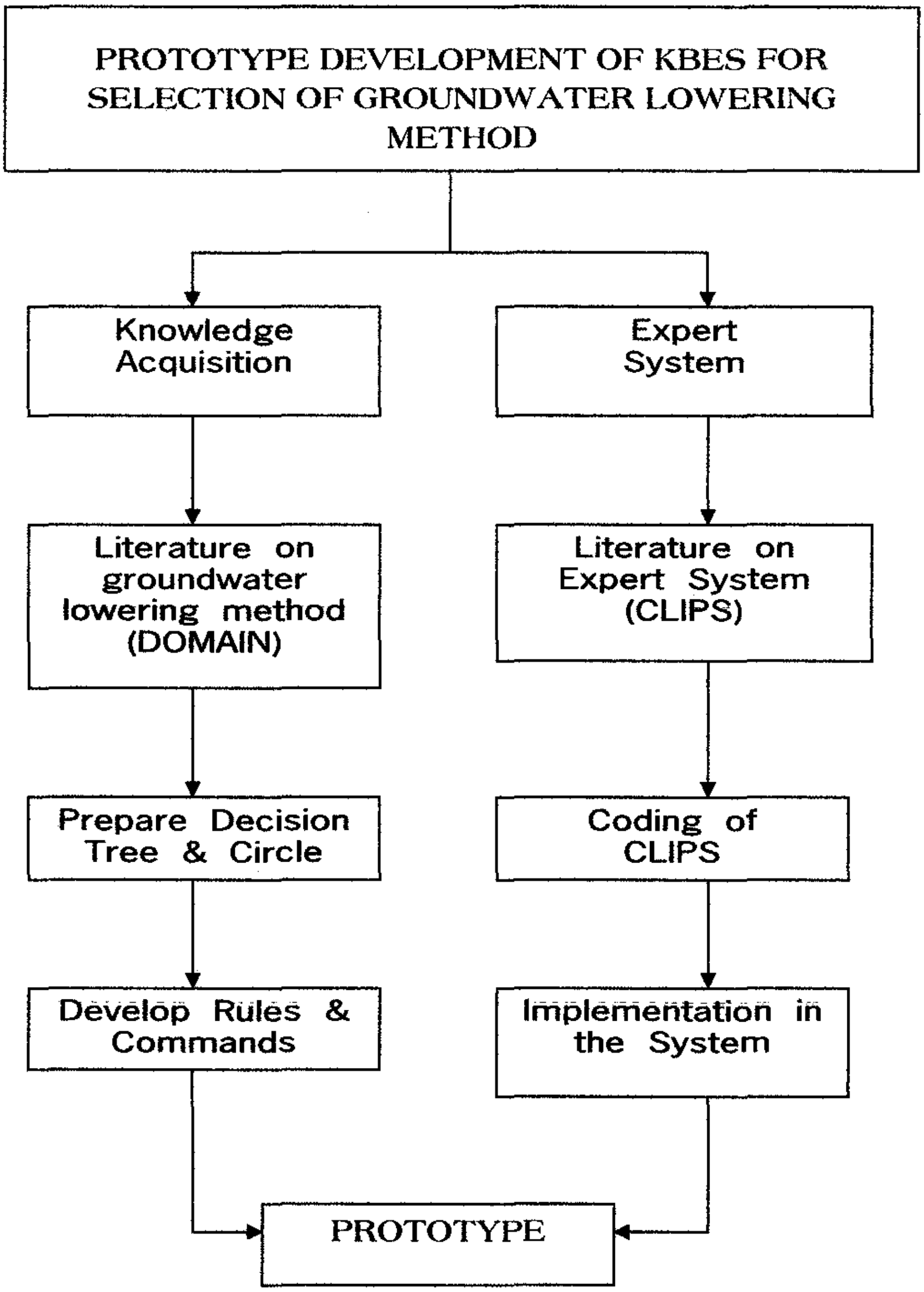

PROTOTYPE DEVELOPMENT OF KBES FOR SELECTION OF GROUNDWATER LOWERING METHOD
Knowledge Acquisition
Expert System
Literature on groundwater lowering method (DOMAIN)
Literature on Expert System (CLIPS)
Prepare Decision Tree & Circle
Coding of CLIPS
Develop Rules & Commands
Implementation in the System
PROTOTYPE

Figure 1: Flow chart of Project Methodology

APPENDIX: 4

Types of Groundwater Lowering System

1) Principal methods for groundwater control by exclusion.

No	Method	Typical Applications	Description
Displacement Barriers			
1	Steel Sheet Piling	Open excavation in most soils, but obstructions such as boulders or timber baulks may impede installation.	May be installed to form permanent cut-off, or used as temporary cut-off with piles removed at the end of construction. Rapid installation. Can support the sides of the excavation with suitable propping. Seal may not be perfect, especially if obstructions present. Vibration and noise of driving may be unacceptable on some sites, but silent methods are available. Relatively cheap.
2	Vibrated Beam Wall	Open excavation in silts and sands. Will not support the soil.	Permanent. A vibrating H-pile is driven into the ground and then removed. As it is removed, grout is injected through nozzles at the toe of the pile to form a thin, low permeability membrane. Rapid installation. Cheap, but cost increase with depth.
Excavated Barriers			
3	Slurry Trench Cut-off Wall using Bentonite or Native Clay	Open excavations in silts, sands and gravels up to a permeability of about $5 \text{ x } 10^{-3} m/s$	Permanent. The slurry trench forms a low permeability curtain wall around the excavation. Quickly installed and relatively cheap, but cost increases rapidly with depth.
4	Structural Concrete diaphragm Walls	Side walls of excavations and shafts in most soils and weak rocks, but presence of boulders may cause problems.	Permanent. Support the sides of excavation and often form the sidewalls of the finished construction. Can be keyed into rock. Minimum noise and vibration. High cost may make method uneconomical unless walls can be incorporated into permanent structure.
5	Secant (interlocking) and Contiguous Bored Piles	As diaphragm walls, but penetration through boulders may be costly and difficult.	As diaphragm walls, but more likely to be economic for temporary works use. Sealing between contiguous piles can be difficult and additional grouting or sealing of joint may be necessary.

Injection Barriers			
6	Jet Grouting	Open excavations in most soils and very weak rocks.	Permanent. Typically forms a series of overlapping columns of soil/grout mixture. Inclined holes possible. Can be messy and create large volumes of slurry. Risk of ground heave if not carried out with care. Relatively expensive.
7	Mix-in-place Columns	Open excavations in most soils and very weak rocks	Permanent. Overlapping columns formed by in-situ mixing of soil and injected grout using auger-based equipment. Produces little spoil. Less flexible than jet grouting. Relatively expensive.
8	Injection Grouting using Cementitious Grouts	Tunnels and shafts in gravels and coarse sands and fissured rocks.	Permanent. The grout fills the pore spaces, preventing the flow of water through the soil. Equipment is simple and can be used in confined spaces. A comparatively thick zone needs to be treated to ensure a continuous barrier is formed. Multiple stages of treatment may be needed.
9	Injection grouting using chemical and solution (acrylic) grouts.	Tunnels and shafts in medium sands (chemical grouts), fine sands and silts (resin grouts)	As cementitious grouting, but materials (chemicals and resin) can be expensive. Silty soils are difficult and treatment may be incomplete, particularly if more permeable laminations or lenses are present.
Other Types			
10	Artificial ground freezing using brine or liquid nitrogen.	Tunnels and shafts. May not work if groundwater flow velocities are excessive (>2 m/day for brine or >20 m/day for liquid nitrogen)	Temporary. A wall of frozen ground (a freeze wall) is formed, which can support the side of the excavations as well as excluding ground water. Liquid nitrogen is to be preferred if groundwater velocities are relatively high. Plant costs are relatively high.
11	Compressed air	Confined chambers such as tunnels, sealed shafts and caissons	Temporary. Increased air pressure (up to 3.5 bars) raises pore water pressure in the soil around the chamber, reducing the hydraulic gradient and limiting groundwater inflow. Potential health hazards to workers. Air losses may be significant in high permeability soils. High running and set up costs.

12	Earth Pressure Balance Tunnel Boring Machine (TBM)	Tunnels in most soils and weak rocks	Temporary. The TBM excavates for the tunnel and supports the soil and excludes groundwater by maintaining as balancing fluid pressure in the plenum chamber immediately behind the cutting head. The fluid is a mixture of soil cuttings, groundwater and conditioning agents (such as polymer or bentonite mud). TBMs need to be carefully selected to deal with given ground conditions; set up and running costs may be high.

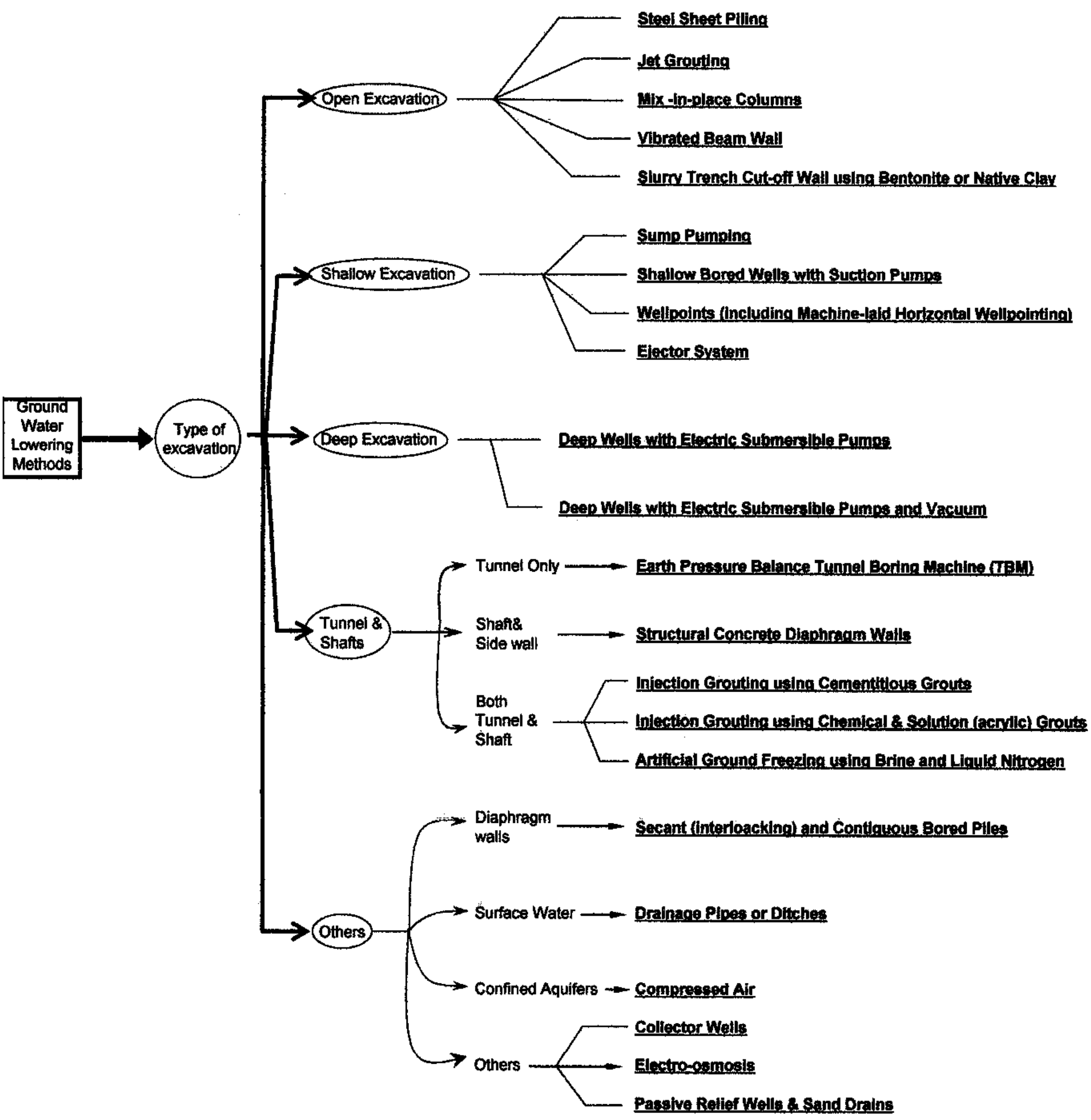
2) Principal methods for groundwater control by dewatering techniques (pumping).

No	Method	Typical Applications	Description
1	Drainage Pipes or Ditches (e.g. French Drains	Control of surface water run-off and shallow groundwater (including over bleed and perched water)	Simple methods of diverting or removing surface water from the working area. May obstruct construction traffic, and will not control groundwater at depth. Unlikely to be effective in reducing pore water pressures in fine-grained soil.
2	Sump Pumping	Shallow excavations in clean coarse soils, for control of groundwater and surface water	Cheap and simple. May not give sufficient drawdown to prevent seepage from emerging on the cut face of a slope, possible leading to loss of fines and instability. May generate silt or sediment laden discharge water, causing environmental problems.
3	Wellpoints (including machine-laid horizontal well pointing)	Generally shallow and open excavation in sandy gravels down to fine sands and possibly silty sands. Deeper excavations (requiring >5-6 m drawdown) will require multiple stages of well points to be installed	Relatively cheap and flexible. Quick and easy to install in sands. Suitable for progressive trench excavations. Difficult to install in ground containing cobbles or boulders. Maximum drawdown is 5-6 m for a single stage in sandy gravels and fine sands, but may only be 4 m in silty sands. Horizontal well pointing suitable for trench excavations outside urban areas, where very rapid installation is possible.
4	Deep wells with electric submersible pumps.	Deep excavations in sandy gravels to fine sands and water bearing fissured rocks.	No limit on drawdown in appropriate soil conditions. Installation costs of wells are significant, but fewer wells may be required compared with most other methods. Close control can be exercised over well screen and filter.

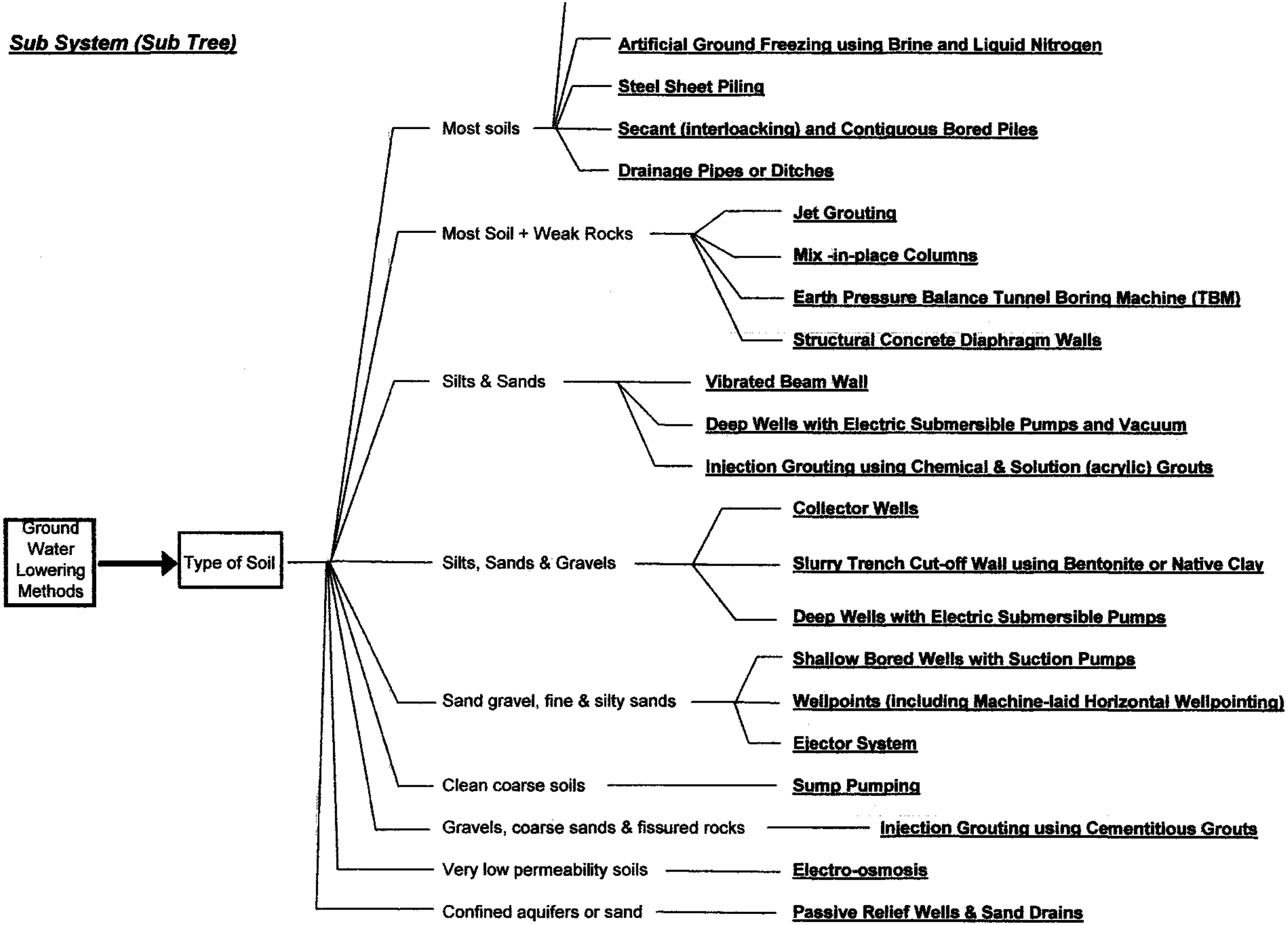
5	Deep wells with electric submersible pumps and vacuum.	Deep excavations in silty fine sands, where drainage from the soil into the well may be slow	No limit on drawdown in appropriate soil conditions. More complex and expensive than ordinary deep wells because of the separate vacuum system. Number of wells may be dictated by the requirement to achieve an adequate drawdown between wells, rather than the flow rate and an ejector system may be more economical.
6	Shallow bored wells with suction pumps	Shallow excavations in sandy gravels to silty fine sands and water-bearing fissured rocks.	Particularly suitable for coarse, high permeability materials where flow rates are likely to be high. Useful where correct filtering is important as closer control can be exercised over the well filter than with well point. Draw downs limited to 4-7 m depending on soil conditions.
7	Ejector system	Excavations in silty fine sands, silts or laminated or fissured clays in which pore water pressure control is required	In practice drawdowns generally limited to 20-50 m depending on equipment. Low energy efficiency, but this is not a problem if flow rates are low. In sealed wells a vacuum is applied to the soil, promoting drainage. Inclined holes possible.
8	Passive relief wells and sand drains	Relief of pore water pressure in confined aquifers or sand lenses below the floor of the excavations to ensure basal stability	Cheap and simple. Create a vertical flow path for water into the excavation; water must then be directed to a sump and pumped away.
9	Collector wells	High permeability sands and gravels	Each collector well is expensive to install, but relatively few wells may produce large flow rates and be able to dewater large areas of site location.
10	Electro-osmosis	Very low permeability soils, e.g. clays, silts and some peats	Only generally used for pore water pressure control or ground improvement when considered as an alternative to artificial ground freezing. Installation and running costs are slightly high.

APPENDIX: 6

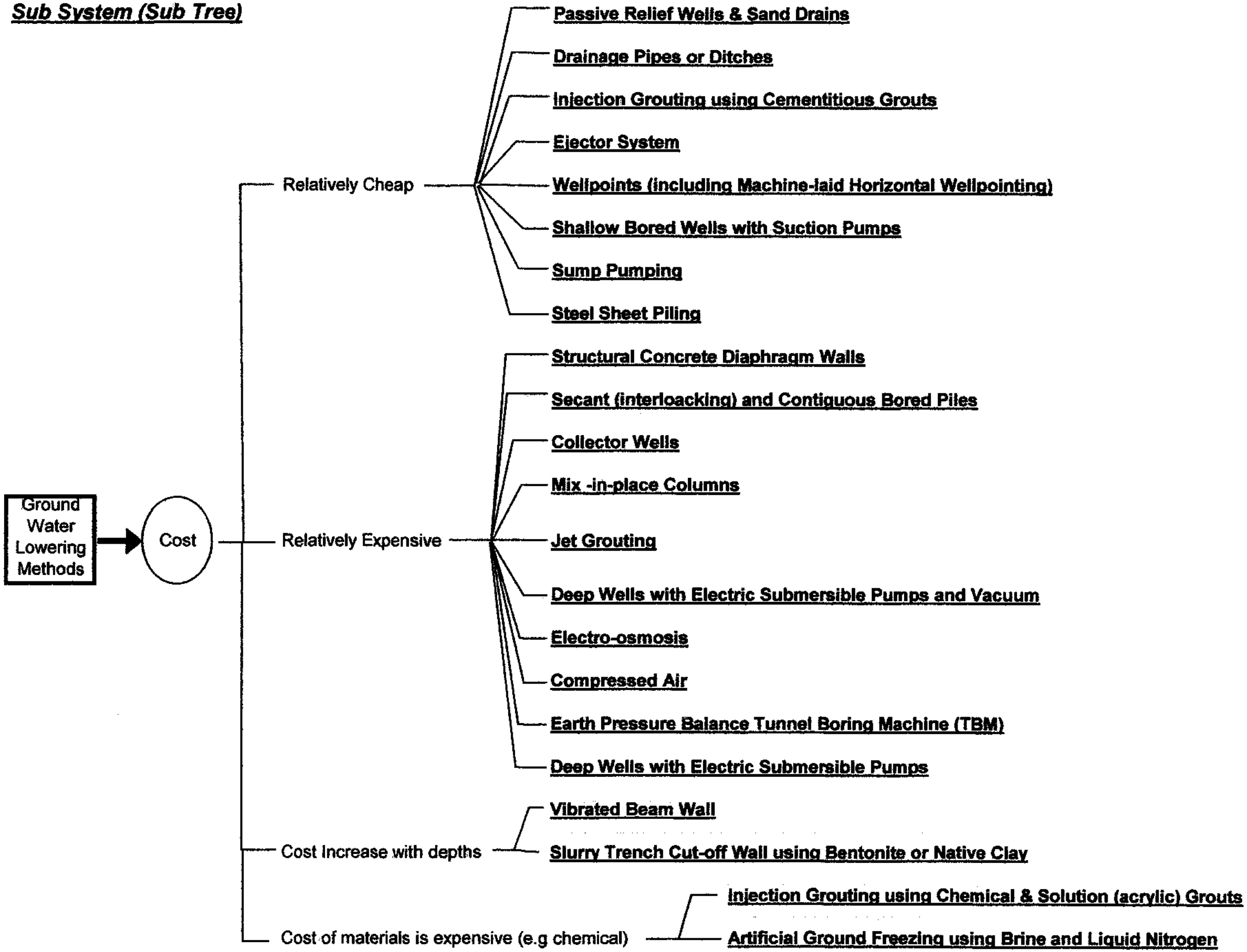
Sub System (Sub Tree)


Ground Water Lowering Methods
Type of excavation
Open Excavation
Steel Sheet Piling
Jet Grouting
Mix -in-place Columns
Vibrated Beam Wall
Slurry Trench Cut-off Wall using Bentonite or Native Clay
Shallow Excavation
Sump Pumping
Shallow Bored Wells with Suction Pumps
Wellpoints (including Machine-laid Horizontal Wellpointing)
Ejector System
Deep Excavation
Deep Wells with Electric Submersible Pumps
Deep Wells with Electric Submersible Pumps and Vacuum
Tunnel & Shafts
Tunnel Only
Earth Pressure Balance Tunnel Boring Machine (TBM)
Shaft& Side wall
Structural Concrete Diaphragm Walls
Both Tunnel & Shaft
Injection Grouting using Cementitious Grouts
Injection Grouting using Chemical & Solution (acrylic) Grouts
Artificial Ground Freezing using Brine and Liquid Nitrogen
Others
Diaphragm walls
Secant (interloacking) and Contiguous Bored Piles
Surface Water
Drainage Pipes or Ditches
Confined Aquifers
Compressed Air
Others
Collector Wells
Electro-osmosis
Passive Relief Wells & Sand Drains

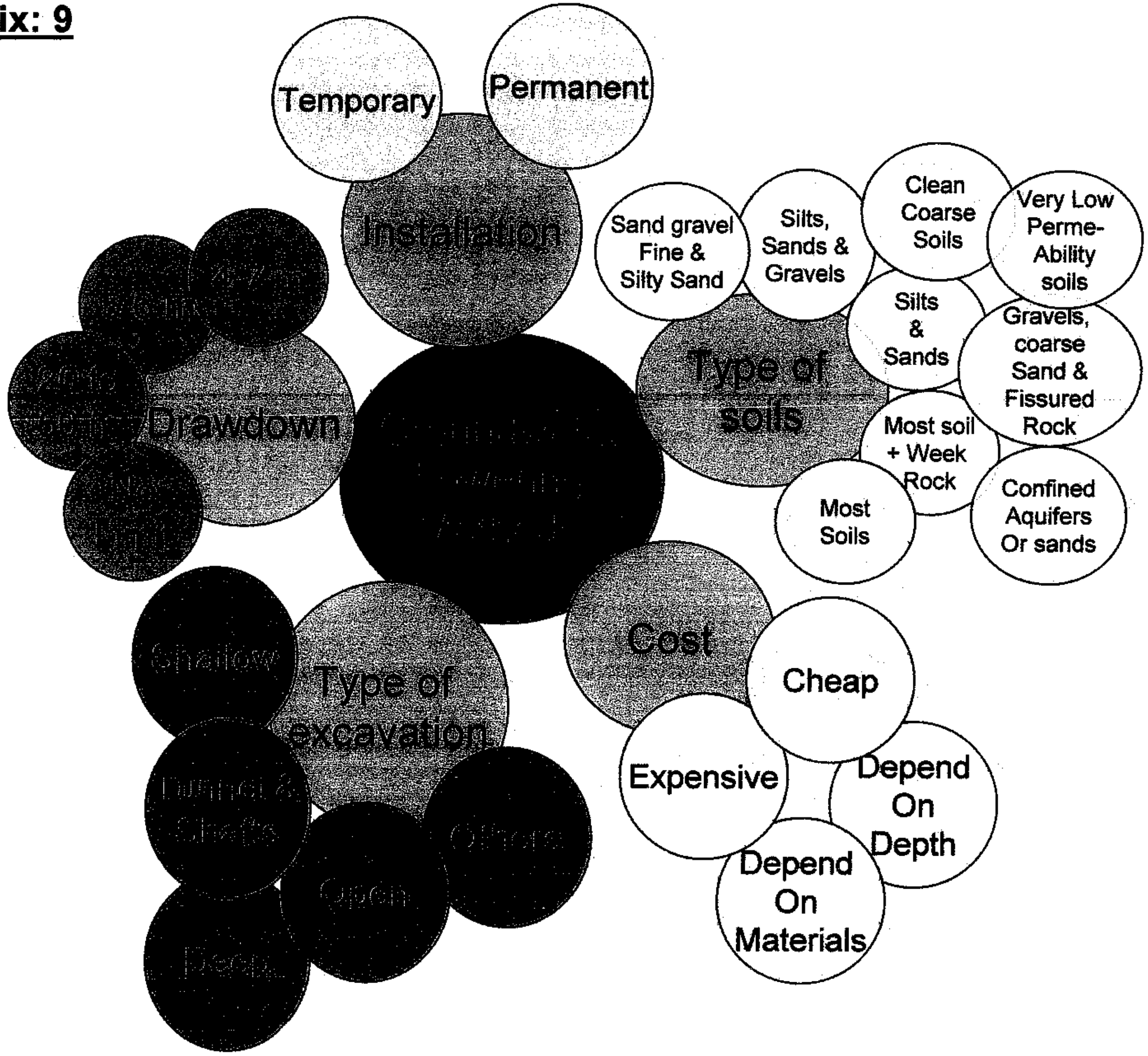
Sub System (Sub Tree)


Ground Water Lowering Methods
Type of Soil
Most soils
Artificial Ground Freezing using Brine and Liquid Nitrogen
Steel Sheet Piling
Secant (interloacking) and Contiguous Bored Piles
Drainage Pipes or Ditches
Most Soil + Weak Rocks
Jet Grouting
Mix -in-place Columns
Earth Pressure Balance Tunnel Boring Machine (TBM)
Structural Concrete Diaphragm Walls
Silts & Sands
Vibrated Beam Wall
Deep Wells with Electric Submersible Pumps and Vacuum
Injection Grouting using Chemical & Solution (acrylic) Grouts
Silts, Sands & Gravels
Collector Wells
Slurry Trench Cut-off Wall using Bentonite or Native Clay
Deep Wells with Electric Submersible Pumps
Sand gravel, fine & silty sands
Shallow Bored Wells with Suction Pumps
Wellpoints (including Machine-laid Horizontal Wellpointing)
Ejector System
Clean coarse soils
Sump Pumping
Gravels, coarse sands & fissured rocks
Injection Grouting using Cementitious Grouts
Very low permeability soils
Electro-osmosis
Confined aquifers or sand
Passive Relief Wells & Sand Drains

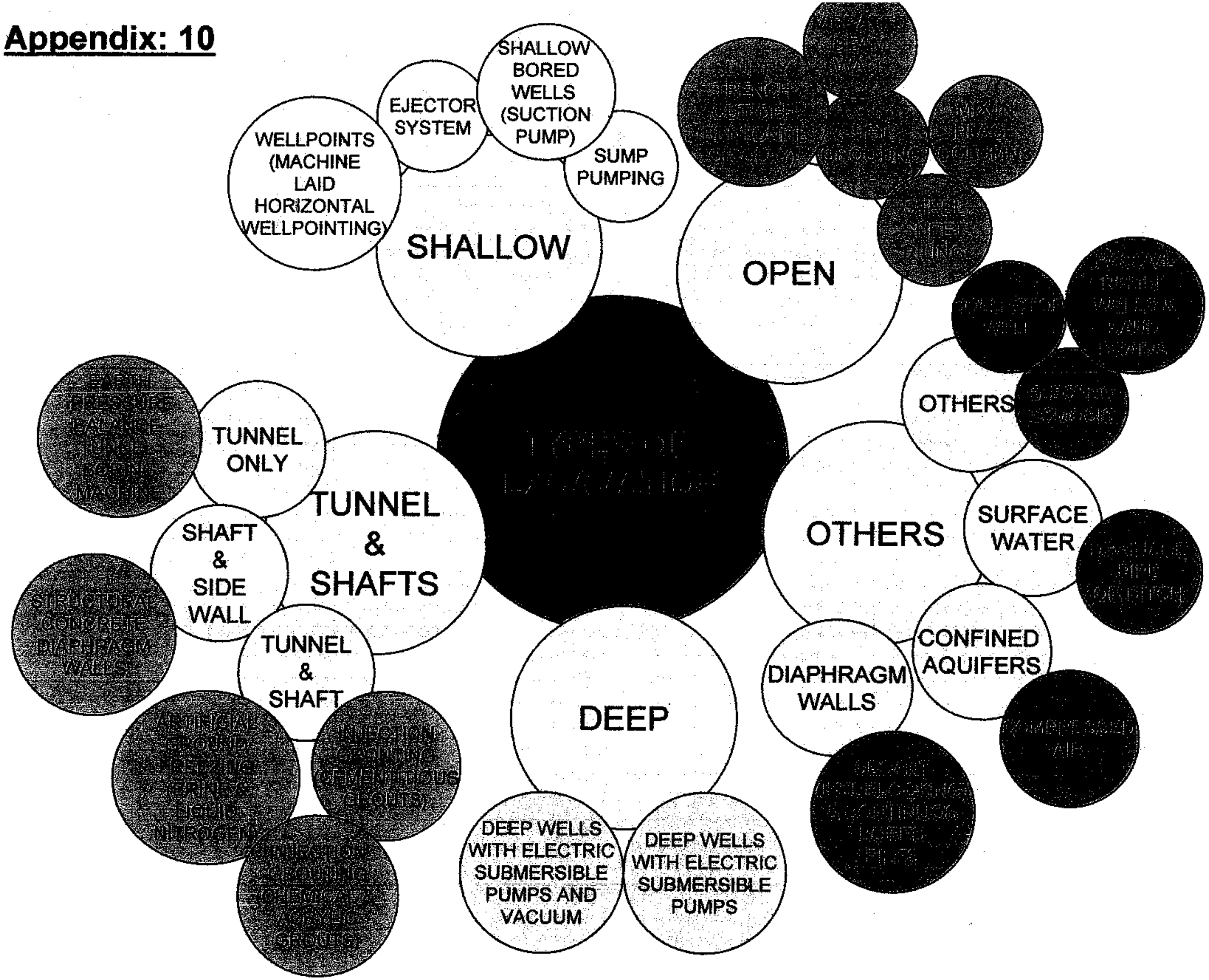
Sub System (Sub Tree)


Ground Water Lowering Methods
Cost
Relatively Cheap
Passive Relief Wells & Sand Drains
Drainage Pipes or Ditches
Injection Grouting using Cementitious Grouts
Ejector System
Wellpoints (including Machine-laid Horizontal Wellpointing)
Shallow Bored Wells with Suction Pumps
Sump Pumping
Steel Sheet Piling
Relatively Expensive
Structural Concrete Diaphragm Walls
Secant (interloacking) and Contiguous Bored Piles
Collector Wells
Mix -in-place Columns
Jet Grouting
Deep Wells with Electric Submersible Pumps and Vacuum
Electro-osmosis
Compressed Air
Earth Pressure Balance Tunnel Boring Machine (TBM)
Deep Wells with Electric Submersible Pumps
Cost Increase with depths
Vibrated Beam Wall
Slurry Trench Cut-off Wall using Bentonite or Native Clay
Cost of materials is expensive (e.g chemical)
Injection Grouting using Chemical & Solution (acrylic) Grouts
Artificial Ground Freezing using Brine and Liquid Nitrogen

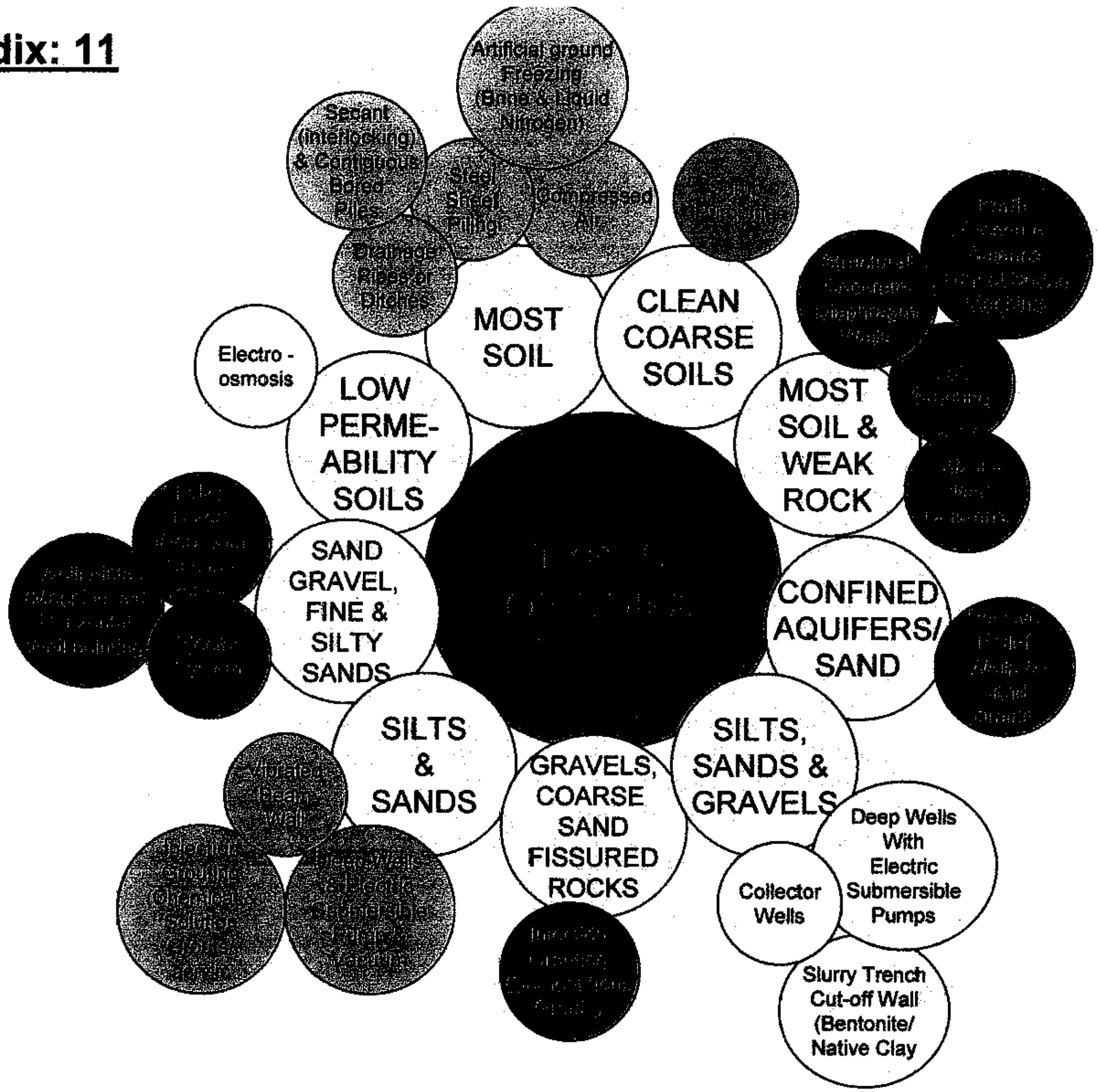
Appendix: 9


Temporary
Permanent
Installation
Drawdown
Type of soils
Sand gravel Fine & Silty Sand
Silts, Sands & Gravels
Clean Coarse Soils
Very Low Perme-Ability soils
Silts & Sands
Gravels, coarse Sand & Fissured Rock
Most soil + Week Rock
Most Soils
Confined Aquifers Or sands
Shallow
Type of excavation
Tunnel & Shafts
Open
Others
Deep
Cost
Cheap
Expensive
Depend On Depth
Depend On Materials

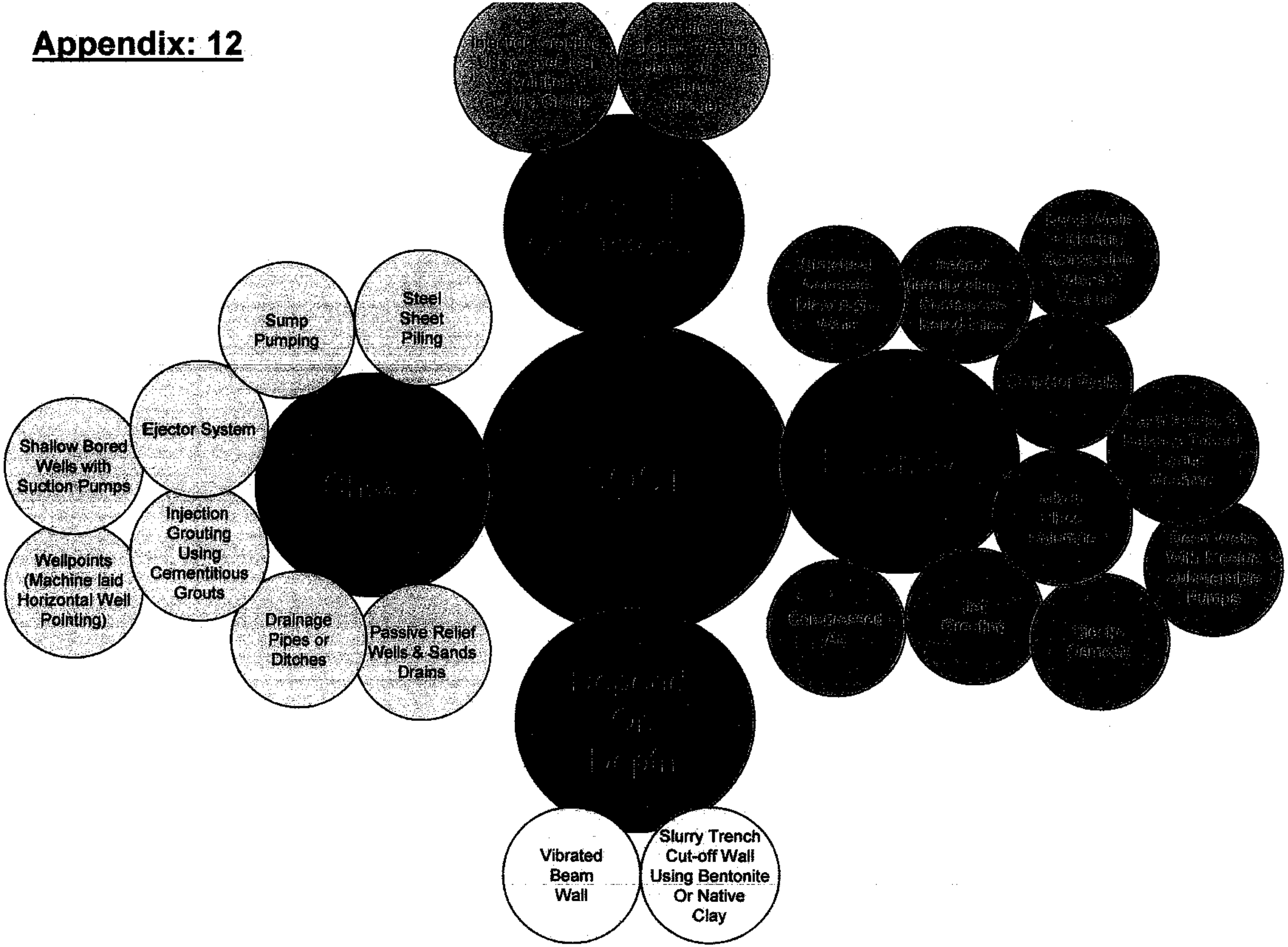
Appendix: 10


TYPES OF EXCAVATION
SHALLOW
WELLPOINTS (MACHINE LAID HORIZONTAL WELLPOINTING)
EJECTOR SYSTEM
SHALLOW BORED WELLS (SUCTION PUMP)
SUMP PUMPING
OPEN
VIBRATED BEAM WALL
SLURRY TRENCH CUT-OFF
GROUTING
MIX IN PLACE COLUMNS
STEEL SHEET PILING
RELIEF WELLS & SAND DRAINS
ELECTRO OSMOSIS
OTHERS
OTHERS
SURFACE WATER
DRAINAGE PIPE
CONFINED AQUIFERS
COMPRESSED AIR
DIAPHRAGM WALLS
SECANT (INTERLOCKING) & CONTIGUOUS BORED PILES
DEEP
DEEP WELLS WITH ELECTRIC SUBMERSIBLE PUMPS AND VACUUM
DEEP WELLS WITH ELECTRIC SUBMERSIBLE PUMPS
TUNNEL & SHAFTS
TUNNEL ONLY
EARTH PRESSURE BALANCE TUNNEL BORING MACHINE
SHAFT & SIDE WALL
STRUCTURAL CONCRETE DIAPHRAGM WALLS
TUNNEL & SHAFT
ARTIFICIAL GROUND FREEZING (BRINE & LIQUID NITROGEN)
INJECTION GROUTING (CEMENTITIOUS GROUTS)
INJECTION GROUTING (CHEMICAL & ACRYLIC GROUTS)

Appendix: 11


Artificial ground Freezing (Brine & Liquid Nitrogen)
Secant (interlocking) & Contiguous Bored Piles
Steel Sheet Piling
Compressed Air
Drainage Pipes or Ditches
MOST SOIL
CLEAN COARSE SOILS
Electro - osmosis
LOW PERME-ABILITY SOILS
MOST SOIL & WEAK ROCK
SAND GRAVEL, FINE & SILTY SANDS
CONFINED AQUIFERS/ SAND
SILTS & SANDS
GRAVELS, COARSE SAND FISSURED ROCKS
SILTS, SANDS & GRAVELS
Vibrated Beam Wall
Deep Wells With Electric Submersible Pumps
Collector Wells
Slurry Trench Cut-off Wall (Bentonite/ Native Clay

Appendix: 12


Sump Pumping
Steel Sheet Piling
Shallow Bored Wells with Suction Pumps
Ejector System
Wellpoints (Machine laid Horizontal Well Pointing)
Injection Grouting Using Cementitious Grouts
Drainage Pipes or Ditches
Passive Relief Wells & Sands Drains
Vibrated Beam Wall
Slurry Trench Cut-off Wall Using Bentonite Or Native Clay
Ejector Wells
Deep Wells With Electric Submersible Pumps
Compressed Air
Jet Grouting
Electro Osmosis

Appendix:13

```
;;====================================================##
;;====================================================##
;; Name       : Siti Norliza binti Ismail             ##
;; Id No      : 3954                                  ##
;; Programme  : Civil Engineering                     ##
;; Supervisor : AP. Dr. Indra Sati Hamonangan Harahap ##
;;                                                    ##
;;              FINAL YEAR PROJECT                    ##
;;                norliza.CLP                         ##
;;          Prototype Development Of                  ##
;;        Knowledge Based Expert System For           ##
;;          Groundwater Lowering Method               ##
;;                                                    ##
;;====================================================##
;;====================================================##
;;
;; Operating instructions:
;;   1.) Execute the CLIPS interpreter.
;;   2.) From the CLIPS prompt, type (load "norliza.clp").
;;   3.) Type (reset) and then (run) to execute the program.
;;
;;**********************************
;; Set up initial facts for testing.
;;**********************************

;;===========================
;;=       Phase # 1         =
;;= (TYPES OF EXCAVATION)   =
;;===========================

(deffacts init
  (troubleshoot-mode excavation)
  (menu-level excavation main))

 (defrule main-menu
  (troubleshoot-mode excavation)
  ?x <- (menu-level excavation main)
=>
 (retract ?x)
 (printout t crlf crlf crlf)
 (printout t
        "The program is designed to help in choosing the best groundwater " crlf
        "lowering methods.  The program will take you step by step through" crlf
        "the procedures to choose the method available." crlf crlf
        "What Type Of Excavation? " crlf
        "  1) Open excavation" crlf
        "  2) Shallow excavation" crlf
        "  3) Deep Excavation" crlf
        "  4) Tunnel & Shaft" crlf
        "  5) Others" crlf
        "  6) or quit the program" crlf crlf
        "Choose 1 - 6 -> ")
  (bind ?response (read))
  (assert (problem-response excavation ?response))
  (retract ?x)
  (printout t crlf))

  (defrule quit
  (troubleshoot-mode excavation)
  ?ml <- (problem-response excavation 6)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-6))
  (assert (problem excavation quit)))

  (defrule possible-causes-1-6
  (troubleshoot-mode excavation)
  (problem-response excavation 6)
=>
  (printout t "You have QUIT the program." crlf)
  (halt))

;===========================================================================
;===========================================================================

;;***************************************************
;;   Variables:                                     *
;;   ?ml - used for retracting the menu level.      *
;;   ?pc - used for retracting the possible cause   *
;;         fact.                                    *
;;   ?type - the type selected by the user.         *
;;***************************************************

;;============================
;;=        Phase # 2         =
;;=     (TYPES OF SOILS)     =
;;============================

;;++++++++++++++++++++++++++++++++++++
;;++     If the user selects 1      ++
;;++   Then the type of excavation  ++
;;++      is OPEN EXCAVATION.       ++
;;++++++++++++++++++++++++++++++++++++
(defrule open
  (troubleshoot-mode excavation)
  ?ml <- (problem-response excavation 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1))
  (assert (problem excavation open)))

;;++++++++++++++++++++++++++++++++++++
;;++     If the user selects 2      ++
;;++   Then the type of excavation  ++
;;++    is SHALLOW EXCAVATION       ++
;;++++++++++++++++++++++++++++++++++++

(defrule shallow
  (troubleshoot-mode excavation)
  ?ml <- (problem-response excavation 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-2))
  (assert (problem excavation shallow)))

;;++++++++++++++++++++++++++++++++++++
;;++     If the user selects 3      ++
;;++   Then the type of excavation  ++
;;++      is DEEP EXCAVATION        ++
;;++++++++++++++++++++++++++++++++++++

(defrule deep
  (troubleshoot-mode excavation)
  ?ml <- (problem-response excavation 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-3))
  (assert (problem excavation deep)))

 ;+++++++++++++++++++++++++++++++++++++
 ;++      If the user selects 4       ++
 ;++    Then the type of excavation   ++
 ;++     is for TUNNEL & SHAFT        ++
 ;+++++++++++++++++++++++++++++++++++++

(defrule tunnel-shaft
  (troubleshoot-mode excavation)
  ?ml <- (problem-response excavation 4)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4))
  (assert (problem excavation tunnel-shaft)))

;;+++++++++++++++++++++++++++++++++++++
;;++      If the user selects 5       ++
;;++    Then the type of excavation   ++
;;++          is for OTHERS           ++
;;+++++++++++++++++++++++++++++++++++++

(defrule others
  (troubleshoot-mode excavation)
  ?ml <- (problem-response excavation 5)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5))
  (assert (problem excavation others)))

;;============================================================================

;;++++++++++++++++++++++++++++++++++++++++++++++++
 ;++              Phase # 2                      ++
 ;++  For this module, the programme will run    ++
 ;++  based on selection for OPEN EXCAVATION     ++
 ;++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule possible-causes-1-1
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1)
  (problem excavation open)
=>
  (printout t crlf crlf crlf)
  (printout t
          "You selected OPEN EXCAVATION as the type of excavation" crlf
          "If you change your mind and would like to review"    crlf
          "the main menu, press 0 now, otherwise select one" crlf
          "of the description that you see from the listed below." crlf crlf
          "What type of soil at site location? " crlf
          "      0.) Return to main menu" crlf
          "      1.) Most soils" crlf
          "      2.) Most soils & weak rocks" crlf
          "      3.) Silts & Sands" crlf
          "      4.) Silts, Sands & Gravels" crlf crlf
          "      Choose 1,2,3 or 4 " crlf)
  (bind ?response (read))
  (assert (possible-cause open ?response))
  (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++
;;++              Phase # 2                         ++
;;++  For this module, the programme will run      ++
 ;++  based on selection for SHALLOW EXCAVATION    ++
 ;+++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule possible-causes-1-2
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2)
  (problem excavation shallow)
=>
  (printout t crlf crlf crlf)
  (printout t
          "You selected SHALLOW EXCAVATION as the type of excavation" crlf
          "If you change your mind and would like to review"    crlf
          "the main menu, press 0 now, otherwise select one" crlf
          "of the description that you see from the listed below." crlf crlf
          "What type of soil at site location? " crlf
        "            0) Return to main menu." crlf
        "            1) Clean coarse soils" crlf
        "            2) Sand gravel, fine & silty sands" crlf crlf
        "            Choose 1 or 2 " crlf)
  (bind ?response (read))
  (assert (possible-cause shallow ?response))
  (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++
;;++              Phase # 2                     ++
;;++  For this module, the programme will run   ++
;;++  based on selection for DEEP EXCAVATION    ++
;;++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule possible-causes-1-3
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-3)
  (problem excavation deep)
=>
  (printout t crlf crlf crlf)
  (printout t
    "You selected DEEP EXCAVATION as the type of excavation" crlf
    "If you change your mind and would like to review"    crlf
    "the main menu, press 0 now, otherwise select one" crlf
    "of the description that you see from the listed below." crlf crlf
    "What type of soil at site location? " crlf
        "   0) Return to main menu." crlf
        "   1) Sandy gravel to fine sands" crlf
        "   2) Silty fine sands" crlf crlf
        "   Choose 1 or 2 " crlf)
  (bind ?response (read))
  (assert (possible-cause deep ?response))
  (printout t crlf))

 ;+++++++++++++++++++++++++++++++++++++++++++++++++
 ;++              Phase # 2                     ++
 ;++  For this module, the programme will run   ++
 ;++  based on selection for TUNNEL & SHAFT     ++
 ;+++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule possible-causes-1-4
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4)
  (problem excavation tunnel-shaft)
=>
  (printout t crlf crlf crlf)
  (printout t
          "You selected TUNNEL & SHAFT as the type of excavation" crlf
          "If you change your mind and would like to review"    crlf
          "the main menu, press 0 now, otherwise select one" crlf
          "of the description that you see from the listed below." crlf crlf
          "What type of tunnels and shafts at site location? " crlf
        "          0) Return to main menu." crlf
        "          1) Tunnel Only" crlf
        "          2) Shaft & Side Wall" crlf
        "          3) Both Tunnel & Shaft" crlf crlf
        "          Choose 1,2 or 3 " crlf)
  (bind ?response (read))
  (assert (possible-cause tunnel-shaft ?response))
  (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++
;;++              Phase # 2                       ++
;;++  For this module, the programme will run     ++
;;++  based on selection for OTHERS EXCAVATION    ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule possible-causes-1-5
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5)
  (problem excavation others)
=>
  (printout t crlf crlf crlf)
  (printout t
          "You selected OTHERS EXCAVATION as the type of excavation" crlf
          "If you change your mind and would like to review"    crlf
          "the main menu, press 0 now, otherwise select one" crlf
          "of the description that you see from the listed below." crlf crlf
          "What type of others excavation is for at site location? " crlf
        "          0) Return to main menu." crlf
        "          1) Diaphragm Walls" crlf
        "          2) Surface Water" crlf
        "          3) Confined Aquifer" crlf
        "          4) Others" crlf crlf
        "          Choose 1,2,3 or 4 " crlf)
  (bind ?response (read))
  (assert (possible-cause open ?response))
  (printout t crlf))

;;===========================================================================
;;===========================================================================

;;***************************************************
;;   Variables:                                     *
;;   ?ml - used for retracting the menu level.      *
;;   ?pc - used for retracting the possible cause   *
;;         fact.                                    *
;;   ?type - the type selected by the user.         *
;;***************************************************

;;=========================================
;;=             Phase # 3                  =
;;= (TYPES OF COST FOR OPEN EXCAVATION)    =
;;=========================================

;;+++++++++++++++++++++++++++++++++++++++++++
;;++              Phase # 3                ++
;;++         (OPEN EXCAVATION)             ++
;;++     If the user selects MOST SOILS    ++
;;+++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-most-soils-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1)
  ?pc <- (possible-cause ?type 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1))
  (retract ?pc)
  (assert (possible-cause ?type most-soils)))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                     Phase # 3                     ++
;;++                (OPEN EXCAVATION)                  ++
;;++     If the user selects MOST SOILS & WEAK ROCKS   ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-most-soils-weak-rocks-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1)
  ?pc <- (possible-cause ?type 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-2))
  (retract ?pc)
  (assert (possible-cause ?type most-soils-weak-rocks)))

;;++++++++++++++++++++++++++++++++++++++++++++++
;;++                 Phase # 3                ++
;;++             (OPEN EXCAVATION)            ++
;;++     If the user selects SILTS & SANDS    ++
;;++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-silts-sands-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1)
  ?pc <- (possible-cause ?type 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-3))
  (retract ?pc)
  (assert (possible-cause ?type silts-sands)))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                     Phase # 3                    ++
;;++                 (OPEN EXCAVATION)                ++
;;++     If the user selects SILTS, SANDS & GRAVEL    ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-silt-sand-gravel-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1)
  ?pc <- (possible-cause ?type 4)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-4))
  (retract ?pc)
  (assert (possible-cause ?type silt-sand-gravel)))

;;===========================================================================

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                      Phase # 3                          ++
;;++        For this module, the programme will run          ++
;;++  based on selection for MOST SOILS IN OPEN EXCAVATION   ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
 (defrule soil-type-most-soils
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1-1)
  ?pc <- (possible-cause ?type most-soils)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected MOST SOILS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
          "      0.) Return to previous menu" crlf
          "      1.) Relatively Cheap" crlf
          "      2.) Relatively Expensive" crlf
          "      3.) Cost increase with depth" crlf crlf
          "      Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                        Phase # 3                        ++
;;++          For this module, the programme will run        ++
;;++       based on selection for MOST SOIL & WEAK ROCKS     ++
;;++                    IN OPEN EXCAVATION                   ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

 (defrule soil-type-most-soils-weak-rocks
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1-2)
  ?pc <- (possible-cause ?type most-soils-weak-rocks)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected MOST SOILS & WEAK ROCKS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
          "     0.) Return to previous menu" crlf
          "     1.) Relatively Cheap" crlf
          "     2.) Relatively Expensive" crlf
          "     3.) Cost increase with depth" crlf crlf
          "     Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                        Phase # 3                        ++
;;++          For this module, the programme will run        ++
;;++            based on selection for SILTS & SANDS         ++
;;++                    IN OPEN EXCAVATION                   ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

 (defrule soil-type-silts-sands
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1-3)
  ?pc <- (possible-cause ?type silts-sands)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected SILTS & SANDS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
          "    0.) Return to previous menu" crlf
          "    1.) Relatively Cheap" crlf
          "    2.) Relatively Expensive" crlf
          "    3.) Cost increase with depth" crlf crlf
          "    Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                      Phase # 3                          ++
;;++        For this module, the programme will run          ++
;;++     based on selection for SILTS, SANDS & GRAVEL        ++
;;++                  IN OPEN EXCAVATION                     ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-silt-sand-gravel
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1-4)
  ?pc <- (possible-cause ?type silt-sand-gravel)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected SILTS, SANDS & GRAVEL as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                  0.) Return to previous menu" crlf
  "                  1.) Relatively Cheap" crlf
  "                  2.) Relatively Expensive" crlf
  "                  3.) Cost increase with depth" crlf crlf
  "                  Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;===========================================================================
;;===========================================================================

;;***************************************************
;;   Variables:                                     *
;;   ?ml - used for retracting the menu level.      *
;;   ?pc - used for retracting the possible cause   *
;;         fact.                                    *
;;   ?type - the type selected by the user.         *
;;***************************************************

;;==================================================
;;=                Phase # 4                       =
;;=  (TYPES OF INSTALLATION FOR OPEN STRUCTURES)   =
;;==================================================

;;++++++++++++++++++++++++++++++++++++++++++++
;;++                Phase # 4               ++
;;++            (OPEN EXCAVATION)           ++
;;++    If the user selects CHEAP METHOD    ++
;;++++++++++++++++++++++++++++++++++++++++++++

(defrule cost-type-cheap-1-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1)
  ?pc <- (possible-cause ?cost 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-1))
  (retract ?pc)
  (assert (possible-cause ?cost cheap)))

;;++++++++++++++++++++++++++++++++++++++++++++++
;;++                Phase # 4                 ++
;;++            (OPEN EXCAVATION)             ++
;;++   If the user selects EXPENSIVE METHOD   ++
;;++++++++++++++++++++++++++++++++++++++++++++++

(defrule cost-type-expensive-1-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1)
  ?pc <- (possible-cause ?cost 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-2))
  (retract ?pc)
  (assert (possible-cause ?cost expensive)))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                    Phase # 4                  ++
;;++                (OPEN EXCAVATION)              ++
;;++    If the user selects COST DEPEND ON DEPTH   ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule cost-type-depend-on-depth-1-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1)
  ?pc <- (possible-cause ?cost 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-3))
  (retract ?pc)
  (assert (possible-cause ?cost depend-on-depth)))

;;============================================================================

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                        Phase # 4                        ++
;;++          For this module, the programme will run        ++
;;++      based on selection for RELATIVELY CHEAP METHOD     ++
;;++                   FOR OPEN EXCAVATION                   ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule cost-type-cheap
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1-1-1)
  ?pc <- (possible-cause ?cost cheap)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You wants the relatively cheap method to lower the groundwater" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "How about installation? Which one do you prefers" crlf
          "     0.) Return to previous menu" crlf
          "     1.) Permanent" crlf
          "     2.) Temporary" crlf
          "     Choose 1 or 2" crlf)
    (bind ?response (read))
    (assert (possible-cause ?cost ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                       Phase # 4                        ++
;;++             For this module, the programme will run    ++
;;++       based on selection for RELATIVELY EXPENSIVE METHOD  ++
;;++                    FOR OPEN EXCAVATION                 ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule cost-type-expensive
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1-1-2)
  ?pc <- (possible-cause ?cost expensive)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You wants the relatively expensive method to lower the groundwater" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "How about installation? Which one do you prefers" crlf
          "    0.) Return to previous menu" crlf
          "    1.) Permanent and flexible" crlf
          "    2.) Permanent but don't mind whether flexible or not" crlf
          "    Choose 1 or 2" crlf)
    (bind ?response (read))
    (assert (possible-cause ?cost ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                    Phase # 4                           ++
;;++           For this module, the programme will run      ++
;;++      based on selection for COST DEPEND ON DEPTH METHOD  ++
;;++                   FOR OPEN EXCAVATION                  ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule cost-type-depend-on-depth
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-1-1-3)
  ?pc <- (possible-cause ?cost depend-on-depth)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You considers the depth of excavation to select the methods" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "How about installation? Which one do you prefers" crlf
          "    0.) Return to previous menu" crlf
          "    1.) Permanent by using H-pile" crlf
          "    2.) Permanent by using Slurry Trench Cut-Off Wall" crlf
          "    Choose 1 or 2" crlf)
    (bind ?response (read))
    (assert (possible-cause ?cost ?response))
    (printout t crlf))

;;===========================================================================
;;===========================================================================

;;***************************************************
```

```
;;   Variables:                                    *
;;   ?ml - used for retracting the menu level.     *
;;   ?pc - used for retracting the possible cause  *
;;         fact.                                   *
;;   ?type - the type selected by the user.        *
;;************************************************

;;===============================================
;;=                Phase # 5                    =
;;=    (DECISION OF METHOD FOR OPEN EXCAVATION)  =
;;===============================================

;;++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                     Phase # 5                  ++
;;++                 (OPEN EXCAVATION)              ++
;;++    If the user selects PERMANENT INSTALLATION  ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule installation-permanent-1-1-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-1)
  ?pc <- (possible-cause ?installation 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-1-1))
  (retract ?pc)
  (assert (possible-cause ?installation permanent)))

;;---------------------------------------------------------
  (defrule installation-temporary-1-1-1-1
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-1)
  ?pc <- (possible-cause ?installation 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-1-2))
  (retract ?pc)
  (assert (possible-cause ?installation temporary)))

;;=============================================================

(defrule installation-permanent
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-1-1)
  ?pc <- (possible-cause ?installation permanent)
=>
  (retract ?ml)
  (retract ?pc)
  (printout t
  "     You wants permanent type of installation. The method that" crlf
  "     suit with this is STEEL SHEET PILING. " crlf
  "     This method can gives rapid installation but it also a" crlf
  "     very noise method and gives vibration" crlf
  "     Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level ecxcavation main)))

 (defrule installation-temporary
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-1-2)
  ?pc <- (possible-cause ?installation temporary)
=>
  (retract ?ml)
  (retract ?pc)
  (printout t
  "     You wants temporary type of installation. The method that" crlf
  "     suit with this is STEEL SHEET PILING. " crlf
  "     This method can gives rapid installation but it also a" crlf
  "     very noise method and gives vibration" crlf
  "     Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level ecxcavation main)))

;;==================================================================
;;==================================================================

  (defrule installation-permanent-flexible-1-1-1-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-2)
  ?pc <- (possible-cause ?installation 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-2-1))
  (retract ?pc)
  (assert (possible-cause ?installation permanent-flexible)))

;;-------------------------------------------------------
  (defrule instruction-permanent-flexible-notflexible-1-1-1-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-2)
  ?pc <- (possible-cause ?installation 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-2-2))
  (retract ?pc)
  (assert (possible-cause ?installation permanent-flexible-notflexible)))

;=======================================================================
  (defrule installation-permanent-flexible
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-2-1)
  ?pc <- (possible-cause ?installation permanent-flexible)
=>
  (retract ?ml)
  (retract ?pc)
  (printout t
  "     You wants permanent and flexible type of installation." crlf
  "     The method that suit with this is JET GROUTING. " crlf
  "     This method will forms overlapping columns." crlf
  "     Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

  (defrule instructions-permanent-flexible-notflexible
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-2-2)
  ?pc <- (possible-cause ?installation permanent-flexible-notflexible)
=>
  (retract ?ml)
  (retract ?pc)
  (printout t
  "     You wants installation that permanent and not consider whether flexible or
not." crlf
  "     The method that suit with this is MIX-IN-PLACE-COLUMS. " crlf
  "     This method will forms overlapping columns." crlf
  "     Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))
```

```
;=======================================================================
;=======================================================================

  (defrule installation-permanent-H-pile-1-1-1-3
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-3)
  ?pc <- (possible-cause ?installation 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-3-1))
  (retract ?pc)
  (assert (possible-cause ?installation permanent-H-pile)))

;;---------------------------------------------------------
  (defrule installation-permanent-slurry-trench-1-1-1-3
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-3)
  ?pc <- (possible-cause ?installation 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-1-1-3-2))
  (retract ?pc)
  (assert (possible-cause ?installation permanent-slurry-trench)))

;;===========================================================================

  (defrule installation-permanent-H-pile
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-3-1)
  ?pc <- (possible-cause ?installation permanent-H-pile)
=>
  (retract ?ml)
  (retract ?pc)
  (printout t
  "     You wants installation that permanent and using H-pile." crlf
  "     The method that suit with this is VIBRATED BEAM WALL. " crlf
  "     This method can gives rapid installation." crlf
  "     Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

  (defrule installation-slurry-trench
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-1-1-3-2)
  ?pc <- (possible-cause ?installation slurry-trench)
=>
  (retract ?ml)
  (retract ?pc)
  (printout t
  "     You wants installation that permanent and using slurry trench cut-off
wall." crlf
  "     The method that suit with this is SLURRY TRENCH CUT-OFF WALL" crlf
  "     USING BENTONITE OR NATIVE CLAY." crlf
  "     This method can gives rapid installation." crlf
  "     Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))


;;===========================================================================
;;===========================================================================

;;**************************************************
```

```
;;   Variables:                                     *
;;    ?ml - used for retracting the menu level.     *
;;    ?pc - used for retracting the possible cause  *
;;          fact.                                   *
;;   ?type - the type selected by the user.         *
;;**************************************************

;;=======================================
;;=              Phase # 4              =
;;= (TYPES OF COST FOR SHALLOW EXCAVATION)    =
;;=======================================

;;+++++++++++++++++++++++++++++++++++++++++++++
;;++                    Phase # 4             ++
;;++              (SHALLOW EXCAVATION)        ++
;;++     If the user selects CLEAN COARSE SOILS   ++
;;+++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-clean-coarse-soils-1-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-2)
  ?pc <- (possible-cause ?type 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-2-1))
  (retract ?pc)
  (assert (possible-cause ?type clean-coarse-soils)))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                            Phase # 4                  ++
;;++                       (SHALLOW EXCAVATION)            ++
;;++     If the user selects SAND GRAVEL, FINE & SILTY SANDS   ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-sand-gravel-fine-and-silty-sands-1-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-2)
  ?pc <- (possible-cause ?type 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-2-2))
  (retract ?pc)
  (assert (possible-cause ?type sand-gravel-fine-and-silty-sands)))

;;=================================================================

;;++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 4                    ++
;;++     For this module, the programme will run       ++
;;++     based on selection for CLEAN COARSE SOILS     ++
;;++                IN SHALLOW EXCAVATION           ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++

 (defrule soil-type-clean-coarse-soils
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2-1)
  ?pc <- (possible-cause ?type clean-coarse-soils)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
        "You have selected CLEAN COARSE SOILS as type of soil at site location"
crlf
        "If you change your mind and would like to review the previous" crlf
```

```
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                    0.) Return to previous menu" crlf
  "                    1.) Relatively Cheap and Simple" crlf
  "                    2.) Relatively Cheap and Flexible" crlf
  "                    3.) Relatively Expensive" crlf
  "                    Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                         Phase # 4                            ++
;;++           For this module, the programme will run            ++
;;++      based on selection for SAND GRAVEL, FINE & SILTY SAND   ++
;;++                      IN SHALLOW EXCAVATION                   ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-sand-gravel-fine-and-silty-sands
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2-2)
  ?pc <- (possible-cause ?type sand-gravel-fine-and-silty-sands)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected SAND GRAVEL, FINE & SILTY SANDS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
          "    0.) Return to previous menu" crlf
          "    1.) Relatively Cheap and Simple" crlf
          "    2.) Relatively Cheap and Flexible" crlf
          "    3.) Relatively Expensive" crlf
          "    Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;============================================================================
;;============================================================================

;;***************************************************
;;   Variables:                                     *
;;   ?ml - used for retracting the menu level.      *
;;   ?pc - used for retracting the possible cause   *
;;         fact.                                    *
;;   ?type - the type selected by the user.         *
;;***************************************************

;;=============================================
;;=             Phase # 5                     =
;;=   (TYPES OF COST FOR DEEP EXCAVATION)     =
;;=============================================

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                         Phase # 5                     ++
;;++                     (DEEP EXCAVATION)                 ++
;;++     If the user selects SANDY GRAVEL TO FINE SANDS    ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-sandy-gravel-to-fine-sands-1-3
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-3)
  ?pc <- (possible-cause ?type 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-3-1))
  (retract ?pc)
  (assert (possible-cause ?type sandy-gravel-to-fine-sands)))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                         Phase # 5                     ++
;;++                     (DEEP EXCAVATION)                 ++
;;++          If the user selects SILTY FINE SANDS         ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-silty-fine-sands-1-3
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-3)
  ?pc <- (possible-cause ?type 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-3-2))
  (retract ?pc)
  (assert (possible-cause ?type silty-fine-sands)))

;;=============================================================================

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 5                        ++
;;++           For this module, the programme will run         ++
;;++      based on selection for SAND GRAVEL TO FINE SAND      ++
;;++                       IN DEEP EXCAVATION                  ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-sandy-gravel-to-fine-sands
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-3-1)
  ?pc <- (possible-cause ?type sandy-gravel-to-fine-sands)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected SANDY GRAVEL TO FINE SANDS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
         "     0.) Return to previous menu" crlf
         "     1.) Relatively Cheap" crlf
         "     2.) Depend on materials used" crlf
         "     3.) Relatively Expensive & more complex" crlf
         "     Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 5                        ++
;;++           For this module, the programme will run         ++
;;++      based on selection for SILTY FINE SANDS              ++
;;++                       IN DEEP EXCAVATION                  ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-silty-fine-sands
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-3-2)
  ?pc <- (possible-cause ?type silty-fine-sands)
```

```
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
        "You have selected SILTY FINE SANDS as type of soil" crlf
        "If you change your mind and would like to review the previous" crlf
        "choices, press 0 now, otherwise select one option below" crlf crlf
        "Do you consider about the cost of the method?" crlf
        "      0.) Return to previous menu" crlf
        "      1.) Relatively Cheap" crlf
        "      2.) Depend on materials used" crlf
        "      3.) Relatively Expensive & more complex" crlf
        "      Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;==============================================================================
;;==============================================================================

;;***************************************************
;;   Variables:                                     *
;;   ?ml - used for retracting the menu level.      *
;;   ?pc - used for retracting the possible cause   *
;;         fact.                                    *
;;   ?type - the type selected by the user.         *
;;***************************************************

;;======================================================
;;=                   Phase # 6                        =
;;=   (TYPES OF SOILS FOR TUNNEL & SHAFT STRUCTURE)    =
;;======================================================

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                       Phase # 6                        ++
;;++                   (TUNNEL & SHAFT)                     ++
;;++     If the user selects TUNNEL STRUCTURE ONLY          ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule structure-type-tunnel-only-1-4
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-4)
  ?pc <- (possible-cause ?tunnel&shafttype 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4-1))
  (retract ?pc)
  (assert (possible-cause ?tunnel&shafttype tunnel-only)))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                       Phase # 6                     ++
;;++                   (TUNNEL & SHAFT)                  ++
;;++     If the user selects SHAFT & SIDE WALL           ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule structure-type-shaft-and-side-wall-1-4
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-4)
  ?pc <- (possible-cause ?tunnel&shafttype 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4-2))
  (retract ?pc)
  (assert (possible-cause ?tunnel&shafttype shaft-and-side-wall)))
```

```
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                        Phase # 6                    ++
;;++                    (TUNNEL & SHAFT)                 ++
;;++     If the user selects BOTH TUNNEL & SHAFT         ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule structure-type-both-tunnel-and-shaft-1-4
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-4)
  ?pc <- (possible-cause ?tunnel&shafttype 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4-3))
  (retract ?pc)
  (assert (possible-cause ?tunnel&shafttype both-tunnel-and-shaft)))

;;===========================================================================

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                         Phase # 6                        ++
;;++          For this module, the programme will run         ++
;;++     based on selection for TUNNEL STRUCTURE ONLY         ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

 (defrule structure-type-tunnel-only
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4-1)
  ?pc <- (possible-cause ?tunnel&shafttype tunnel-only)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected TUNNEL ONLY as type of structure" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "What type of soil at site location? " crlf
        "       0) Return to main menu." crlf
        "       1) Most Soils" crlf
        "       2) Most Soils & Weak Rocks" crlf
        "       3) Gravel, Coarse Sands & Fissured Rocks" crlf
        "       4) Medium Sands & Fine Silts" crlf crlf
        "       Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?tunnel&shafttype ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                    Phase # 6                        ++
;;++     For this module, the programme will run         ++
;;++    based on selection for SHAFT & SIDE WALL         ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule structure-type-shaft-and-side-wall
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4-2)
  ?pc <- (possible-cause ?tunnel&shafttype shaft-and-side-wall)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected SHAFT AND SIDE WALL as type of structure" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "What type of soil at site location? " crlf
        "       0) Return to main menu." crlf
        "       1) Most Soils" crlf
        "       2) Most Soils & Weak Rocks" crlf
        "       3) Gravel, Coarse Sands & Fissured Rocks" crlf
        "       4) Medium Sands & Fine Silts" crlf crlf
        "       Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?tunnel&shafttype ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 6                        ++
;;++       For this module, the programme will run      ++
;;++     based on selection for BOTH TUNNEL & SHAFT     ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule structure-type-both-tunnel-and-shaft
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4-3)
  ?pc <- (possible-cause ?tunnel&shafttype both-tunnel-and-shaft)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected BOTH TUNNEL AND SHAFT as type of structure" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "What type of soil at site location? " crlf
        "       0) Return to main menu." crlf
        "       1) Most Soils" crlf
        "       2) Most Soils & Weak Rocks" crlf
        "       3) Gravel, Coarse Sands & Fissured Rocks" crlf
        "       4) Medium Sands & Fine Silts" crlf crlf
        "       Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?tunnel&shafttype ?response))
    (printout t crlf))

;;===========================================================================
;;===========================================================================

;;***************************************************
;;   Variables:                                     *
;;   ?ml - used for retracting the menu level.      *
;;   ?pc - used for retracting the possible cause   *
;;         fact.                                    *
;;   ?type - the type selected by the user.         *
;;***************************************************

;;==============================================
;;=                 Phase # 7                  =
;;=   (TYPES OF SOILS FOR OTHERS STRUCTURE)    =
;;==============================================

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                       Phase # 7                    ++
;;++                   (OTHER STRUCTURES)               ++
;;++     If the user selects DIAPHRAGM WALLS            ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule structure-type-diaphragm-walls-1-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5)
  ?pc <- (possible-cause ?otherstype 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-1))
  (retract ?pc)
  (assert (possible-cause ?otherstype diaphragm-walls)))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                    Phase # 7                    ++
;;++                (OTHER STRUCTURES)               ++
;;++        If the user selects SURFACE WATER        ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule structure-type-surface-water-1-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5)
  ?pc <- (possible-cause ?otherstype 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-2))
  (retract ?pc)
  (assert (possible-cause ?otherstype surface-water)))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                    Phase # 7                    ++
;;++                (OTHER STRUCTURES)               ++
;;++     If the user selects CONFINED AQUIFERS       ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule structure-type-confined-aquifer-1-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5)
  ?pc <- (possible-cause ?otherstype 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-3))
  (retract ?pc)
  (assert (possible-cause ?otherstype confined-aquifer)))

;;+++++++++++++++++++++++++++++++++++++++++++
;;++               Phase # 7               ++
;;++          (OTHER STRUCTURES)           ++
;;++    If the user selects OTHERS         ++
;;+++++++++++++++++++++++++++++++++++++++++++

(defrule structure-type-others-1-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5)
  ?pc <- (possible-cause ?otherstype 4)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-4))
  (retract ?pc)
  (assert (possible-cause ?otherstype others)))

;;===========================================================================

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 7                        ++
;;++       For this module, the programme will run      ++
;;++        based on selection for DIAPHRAGM WALLS      ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

 (defrule structure-type-diaphragm-walls
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-1)
  ?pc <- (possible-cause ?otherstype diaphragm-walls)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected DIAPHRAGM WALLS as type of structure" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "What type of soil at site location? " crlf
        "            0) Return to main menu." crlf
        "            1) Most soils" crlf
        "            2) High permeability sands & gravel" crlf crlf
        "            3) Very low permeability soils" crlf
        "            4) Confined aquifers or sand" crlf crlf
        "            Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?otherstype ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 7                        ++
;;++       For this module, the programme will run      ++
;;++        based on selection for SURFACE WATER        ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule structure-type-surface-water
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-2)
  ?pc <- (possible-cause ?otherstype surface-water)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected SURFACE WATER as type of excavation" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "What type of soil at site location? " crlf
        "            0) Return to main menu." crlf
        "            1) Most soils" crlf
        "            2) High permeability sands & gravel" crlf crlf
        "            3) Very low permeability soils" crlf
        "            4) Confined aquifers or sand" crlf crlf
        "            Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?otherstype ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 7                      ++
;;++       For this module, the programme will run    ++
;;++       based on selection for CONFINED AQUIFERS   ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule structure-type-confined-aquifers
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-3)
  ?pc <- (possible-cause ?otherstype confined-aquifers)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected CONFINED AQUIFERS as type of excavation" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "What type of soil at site location? " crlf
        "            0) Return to main menu." crlf
        "            1) Most soils" crlf
        "            2) High permeability sands & gravel" crlf crlf
        "            3) Very low permeability soils" crlf
        "            4) Confined aquifers or sand" crlf crlf
        "            Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?otherstype ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 7                      ++
;;++       For this module, the programme will run    ++
;;++           based on selection for OTHERS          ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule structure-type-others
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-3)
  ?pc <- (possible-cause ?otherstype others)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected OTHERS type of excavation except stated before" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "What type of soil at site location? " crlf
        "            0) Return to main menu." crlf
        "            1) Most soils" crlf
        "            2) High permeability sands & gravel" crlf crlf
        "            3) Very low permeability soils" crlf
        "            4) Confined aquifers or sand" crlf crlf
        "            Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?otherstype ?response))
    (printout t crlf))

;;===========================================================================
;;===========================================================================

;;***************************************************
;;   Variables:                                     *
;;   ?ml - used for retracting the menu level.      *
;;   ?pc - used for retracting the possible cause   *
;;         fact.                                    *
;;   ?type - the type selected by the user.         *
;;***************************************************

;;============================================
;;=                Phase # 8                  =
;;=   (TYPES OF COST FOR TUNNEL & SHAFT )     =
;;============================================

;;+++++++++++++++++++++++++++++++++++++++++++
;;++               Phase # 8               ++
;;++      (TUNNEL & SHAFT STRUCTURES)      ++
;;++     If the user selects MOST SOILS    ++
;;+++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-most-soils-1-4-4
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-4-4)
  ?pc <- (possible-cause ?type 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4-4-1))
  (retract ?pc)
  (assert (possible-cause ?type most-soils)))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                       Phase # 8                    ++
;;++              (TUNNEL & SHAFT STRUCTURES)           ++
;;++    If the user selects MOST SOILS & WEAK ROCKS     ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-most-soils-and-weak-rocks-1-4-4
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-4-4)
  ?pc <- (possible-cause ?type 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4-4-2))
  (retract ?pc)
  (assert (possible-cause ?type most-soils-and-weak-rocks)))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 8                       ++
;;++                (TUNNEL & SHAFT STRUCTURES)               ++
;;++    If the user selects COARSE SANDS & FISSURED ROCKS     ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-gravel-coarse-sands-and-fissured-rocks-1-4-4
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-4-4)
  ?pc <- (possible-cause ?type 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4-4-3))
  (retract ?pc)
  (assert (possible-cause ?type gravel-coarse-sands-and-fissured-rocks)))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                     Phase # 8                      ++
;;++            (TUNNEL & SHAFT STRUCTURES)             ++
;;++    If the user selects MEDIUM SANDS & FINE SILTS   ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-medium-sands-and-fine-silts-1-4-4
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-4-4)
  ?pc <- (possible-cause ?type 4)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-4-4-4))
  (retract ?pc)
  (assert (possible-cause ?type medium-sands-and-fine-silts)))

;;===========================================================================

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 8                        ++
;;++       For this module, the programme will run      ++
;;++         based on selection for MOST SOILS          ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++
  (defrule soil-type-most-soils
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4-4-1)
  ?pc <- (possible-cause ?type most-soils)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected MOST SOILS as type of soil at site location" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                    0.) Return to previous menu" crlf
  "                    1.) Relatively Cheap" crlf
  "                    2.) Relatively Expensive" crlf
  "                    3.) Depend on materials used" crlf crlf
  "                    Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                      Phase # 8                           ++
;;++         For this module, the programme will run          ++
;;++      based on selection for MOST SOILS & WEAK ROCKS      ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-most-soils-and-weak-rocks
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4-4-2)
  ?pc <- (possible-cause ?type most-soils-and-weak-rocks)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected MOST SOILS AND WEAK ROCKS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                    0.) Return to previous menu" crlf
  "                    1.) Relatively Cheap" crlf
  "                    2.) Relatively Expensive" crlf
  "                    3.) Depend on materials used" crlf crlf
  "                    Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 8                              ++
;;++           For this module, the programme will run               ++
;;++  based on selection for GRAVEL COARSE SANDS & FISSURED ROCKS    ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-gravel-coarse-sands-and-fissured-rocks
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4-4-3)
  ?pc <- (possible-cause ?type gravel-coarse-sands-and-fissured-rocks)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected GRAVEL,COARSE SANDS & FISSURED ROCKS as type of soil"
crlf
```

```
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                 0.) Return to previous menu" crlf
  "                 1.) Relatively Cheap" crlf
  "                 2.) Relatively Expensive" crlf
  "                 3.) Depend on materials used" crlf crlf
  "                 Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                         Phase # 8                        ++
;;++        For this module, the programme will run           ++
;;++    based on selection for MEDIUM SANDS & FINE SILTS      ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-medium-sands-and-fine-silts
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-4-4-4)
  ?pc <- (possible-cause ?type medium-sands-and-fine-silts)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected MEDIUM SANDS & FINE SILTS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                 0.) Return to previous menu" crlf
  "                 1.) Relatively Cheap" crlf
  "                 2.) Relatively Expensive" crlf
  "                 3.) Depend on materials used" crlf crlf
  "                 Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;==========================================================================
;;==========================================================================

;;**************************************************
;;   Variables:                                    *
;;   ?ml - used for retracting the menu level.     *
;;   ?pc - used for retracting the possible cause  *
;;         fact.                                   *
;;   ?type - the type selected by the user.        *
;;**************************************************

;;=============================================
;;=                Phase # 9                  =
;;=   (TYPES OF COST FOR OTHERS STRUCTURES)   =
;;=============================================

;;+++++++++++++++++++++++++++++++++++++++++++
;;++                Phase # 9              ++
;;++          (OTHERS STRUCTURES)          ++
;;++    If the user selects MOST SOILS     ++
;;+++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-most-soils-1-5-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5-5)
  ?pc <- (possible-cause ?type 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-5-1))
  (retract ?pc)
  (assert (possible-cause ?type most-soils)))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 9                       ++
;;++                     (OTHERS STRUCTURES)                  ++
;;++    If the user selects HIGH PERMEABILITY SAND & GRAVEL   ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-high-permeability-sand-and-gravel-1-5-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5-5)
  ?pc <- (possible-cause ?type 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-5-2))
  (retract ?pc)
  (assert (possible-cause ?type high-permeability-sand-and-gravel)))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 9                       ++
;;++                     (OTHERS STRUCTURES)                  ++
;;++    If the user selects VERY LOW PERMEABILITY SOILS       ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-very-low-permeability-soils-1-5-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5-5)
  ?pc <- (possible-cause ?type 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-5-3))
  (retract ?pc)
  (assert (possible-cause ?type very-low-permeability-soils)))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                       Phase # 9                     ++
;;++                  (OTHERS STRUCTURES)                ++
;;++    If the user selects CONFINE AQUIFERS OR SANDS    ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-confined-aquifers-or-sands-1-5-5
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-5-5)
  ?pc <- (possible-cause ?type 4)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-5-5-4))
  (retract ?pc)
  (assert (possible-cause ?type confined-aquifers-or-sands)))

;;===========================================================================

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                   Phase # 9                     ++
;;++     For this module, the programme will run     ++
;;++        based on selection for MOST SOILS        ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++

(defrule soil-type-most-soils
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-5-1)
  ?pc <- (possible-cause ?type most-soils)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected MOST SOILS as type of soil at site location" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                    0.) Return to previous menu" crlf
  "                    1.) Relatively Cheap and simple" crlf
  "                    2.) Relatively Expensive" crlf
  "                    3.) Depend on materials and equipment used" crlf crlf
  "                    Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 9                            ++
;;++            For this module, the programme will run            ++
;;++  based on selection for HIGH PERMEABILITY SANDS & GRAVEL       ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-high-permeability-sands-and-gravel
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-5-2)
  ?pc <- (possible-cause ?type high-permeability-sands-and-gravel)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected HIGH PERMEABILITY SANDS & GRAVEL as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                    0.) Return to previous menu" crlf
  "                    1.) Relatively Cheap and simple" crlf
  "                    2.) Relatively Expensive" crlf
  "                    3.) Depend on materials and equipment used" crlf crlf
  "                    Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                          Phase # 9                            ++
;;++            For this module, the programme will run            ++
;;++      based on selection for VERY LOW PERMEABILITY SOILS       ++
;;++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-very-low-permeability-soils
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-5-3)
  ?pc <- (possible-cause ?type very-low-permeability-soils)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected  as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                 0.) Return to previous menu" crlf
  "                 1.) Relatively Cheap and simple" crlf
  "                 2.) Relatively Expensive" crlf
  "                 3.) Depend on materials and equipment used" crlf crlf
  "                 Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))

;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
;;++                        Phase # 9                          ++
;;++            For this module, the programme will run        ++
;;++        based on selection for CONFINED AQUIFERS OR SANDS    ++
;;+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

  (defrule soil-type-confined-aquifers-or-sands
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-5-5-4)
  ?pc <- (possible-cause ?type confined-aquifers-or-sands)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected CONFINED AQUIFERS OR SANDS as type of soil" crlf
          "If you change your mind and would like to review the previous" crlf
          "choices, press 0 now, otherwise select one option below" crlf crlf
          "Do you consider about the cost of the method?" crlf
  "                 0.) Return to previous menu" crlf
  "                 1.) Relatively Cheap and simple" crlf
  "                 2.) Relatively Expensive" crlf
  "                 3.) Depend on materials and equipment used" crlf crlf
  "                 Choose 1,2 or 3" crlf)
    (bind ?response (read))
    (assert (possible-cause ?type ?response))
    (printout t crlf))


;;===============================================================================

(defrule drawdown-no-limit-1-2-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-2-2)
  ?pc <- (possible-cause ?drawdowntype 1)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-2-2-1))
  (retract ?pc)
  (assert (possible-cause ?drawdowntype no-limit))
;;------------------------------------------------------------

(defrule drawdown-4m-to-7m-1-2-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-2-2)
  ?pc <- (possible-cause ?drawdowntype 2)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-2-2-2))
  (retract ?pc)
  (assert (possible-cause ?drawdowntype 4m-to-7m))

;;------------------------------------------------------------
```

```
(defrule drawdown-5m-to-6m-1-2-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-2-2)
  ?pc <- (possible-cause ?drawdowntype 3)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-2-2-3))
  (retract ?pc)
  (assert (possible-cause ?drawdowntype 5m-to-6m))

 ;;------------------------------------------------------

 (defrule drawdown-20m-to-50m-1-2-2
  (troubleshoot-mode excavation)
  ?ml <- (menu-level excavation possible-causes-1-2-2)
  ?pc <- (possible-cause ?drawdowntype 4)
=>
  (retract ?ml)
  (assert (menu-level excavation possible-causes-1-2-2-4))
  (retract ?pc)
  (assert (possible-cause ?drawdowntype 20m-to-50m))

;;=======================================================================
  (defrule drawdown-no-limit
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2-2-1)
  ?pc <- (possible-cause ?drawdowntype no-limit)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
        " You choosed the method that cheap and simple" crlf
        " The type of drawdown is: " crlf
        "    0.) Return to previous menu" crlf
        "    1.) No sufficient limit" crlf
        "    2.) Drawdown is 4 to 7 m " crlf
        "    3.) Drawdown is 5-6 m in sandy gravel" crlf
        "        & fine sands and 4 m in silty sands" crlf
        "    4.) Drawdown up to 20 to 50 m" crlf
        "    Choose 1,2,3 or 4 " crlf)
    (bind ?response (read))
    (assert (possible-cause ?drawdowntype ?response))
    (printout t crlf))

 (defrule instruction-no-limit
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2-2-1)
  ?pc <- (possible-cause ?cost cheap-simple)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected CHEAP AND SIMPLE methods." crlf
          "The method that suit is SUMP PUMPING method" crlf
          "But this method does'nt give sufficient drawdown" crlf
          "and it also can cause environmental problems" crlf crlf
          "Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

  (defrule drawdown-type-4m-to-7m
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2-2-2-2)
  ?pc <- (possible-cause ?drawdown 4-to-7m)
```

```
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected method that gives 4 to 7 m drawdown." crlf
          "The method that suit is SHALLOW BORED WELLS WITH SUCTION PUMPS method"
crlf
          "But this method suitable for coarse and high permeability materials "
crlf
          "Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

  (defrule drawdown-type-5m-to-6m
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2-2-2-3)
  ?pc <- (possible-cause ?drawdown 5-to-6m)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected method that gives 5 to 6 m drawdown in" crlf
          "sandy gravel and fine sands and 4 m in silty sands." crlf
          "The method is WELLPOINTS (INCLUDING MACHINE-LAID HORIZONTAL
WELLPOINTING)" crlf
          "This method suitable for progressive trench excavations " crlf
          "Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

  (defrule drawdown-type-20m-to-50m
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-2-2-2-4)
  ?pc <- (possible-cause ?drawdown 20-to-50m)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected method that gives 20 to 50 m drawdown." crlf
          "The method is suit is EJECTOR SYSTEM METHOD" crlf
          "This method have low energy efficiency " crlf
          "Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

================================================================================

  (defrule cost-type-cheap
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-3-3-1)
  ?pc <- (possible-cause ?cost cheap)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected CHEAP methods." crlf
          "The method that suit is DEEP WELL WITH ELECTRIC SUBMERSIBLE PUMPS" crlf
          "But this method have no limit of drawdown" crlf
          "Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

  (defrule cost-type-depend-on-materials
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-3-3-2)
  ?pc <- (possible-cause ?cost depend-on-materials)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected methods that the cost depend on materials." crlf
          "The method that suit is DEEP WELL WITH ELECTRIC SUBMERSIBLE PUMPS" crlf
          "But this method have no limit of drawdown" crlf
          "Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))

  (defrule cost-type-expensive
  (troubleshoot-mode excavation)
  (menu-level excavation possible-causes-1-3-3-3)
  ?pc <- (possible-cause ?cost expensive)
=>
  (retract ?pc)
  (printout t crlf crlf crlf)
  (printout t
          "You have selected methods that the cost depend on materials." crlf
          "The method that suit is DEEP WELL WITH ELECTRIC SUBMERSIBLE PUMPS &
VACUUM" crlf
          "But this method have no limit of drawdown" crlf
          "Press return to view main menu." crlf)
  (bind ?response (readline))
  (assert (menu-level excavation main)))
```

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