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Stručni članak

REDUCTION OF COST AND TIME CONSUMPTION IN WELL-CONSTRUCTION

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Key-words: Drilling bit, Drilling method, Well, Screen, Casing, Design of well, Well diameter

A Contractor usually utilizes the available drilling equipment when constructing just one single well. Drilling cost and time consumption in constructing the well MB-1, using the percussion method, and the well MB-2, using the conventional rotary drilling method, call for a separate analysis in order to justify the investment cost for the acquisition of additional equipment for a single well only. The wells, located in a karst vrtača close to an estavelle near Tomislavgrad, with a diameter of 500 mm and approximately 80 m deep, have been accomplished with a low rate of penetration using the conventional Cable tool and resp. Rotary Drilling Method. In this paper results of analyses for the given circumstances are shown: both the efficiency and cost of the mentioned drilling methods performed by the crews of »Geotehnika d.d.« Zagreb, as well as the justifiability of investments in new equipment are evaluated.

Ključne riječi: Bušaće dlijeto, Metoda bušenja, Zdenac, Filter, Kolona, Konstrukcija zdenca, Promjer zdenca

Izvoditelj obično rabi raspoloživo bušaće postrojenje i alatke za bušenje pojedinačnog zdenca. Troškovi i trajanje izvedbe zdenaca MB-1 udarnom metodom i MB-2 rotacijskom metodom bušenja zahtijevaju posebnu analizu radi procjene opravdanosti investiranja u nabavu dodatne opreme za izvedbu pojedinačnih zdenaca u danim uvjetima. Ovi zdenci, 500 mm promjera i približno 80 m dubine, locirani su u krškoj vrtači u blizini estavele kod Tomislavgrada i nisu učinkovito izvedeni klasičnim postrojenjima udarne BM-1, niti rotacijske metode bušenja BM-2. Ovdje se daju rezultati analiza učinaka i troškova izvedbe zdenaca načinima koje su iskušale bušaće ekipe poduzeća »Geotehnika d.d.« Zagreb te opravdanost investiranja u nabavu dodatne opreme.

Introduction

USA National Water Well Association (NWWA) found numerous deficiencies in well construction including: insufficient and substandard well casing, inadequate screen positioning, inadequate seal between the well casing and the bore hole, poor welding of casing joints, lack of sanitary covers etc. Any of these deficiencies may allow introduction of bacterial contamination of ground water (USEPA, 1977). NWWA is concerned if water well drillers and groundwater specialists use the construction procedure, which could affect public health. Therefore, they prepared a set of generally accepted specifications for well construction that could be widely used by water well contractors, consulting engineers, hydrogeologists, and municipalities to upgrade existing well construction techniques and afford a greater protection of groundwater reserves.

The outlined well construction practices are supported by USEPA as being complete and environmentally sound. Beside the technical criteria with »Master Key« to obtain the appropriate language for preparing water well specification, the manual describes the methodology by which a contractor may be engaged to construct a water well (USEPA, 1977).

Many groundwater aquifers in Croatia are well studied and developed, but at present it does not exist any manual with standard specification of water well, or any published procedure for an efficient bidding and/or contraction for the implementation of wells. The National Agency for Water Management, »Hrvatske vode« (HV), is the owner of water wells MB-1 and MB-2 in Mukišnica near Tomislavgrad. These wells have been drilled to investigate and draw water from a transboundary karst aquifer to provide drinking water in 15 villages in Croatia and 14 villages in Bosnia and Hercegovina.

The selected contractor for implementation of MB-1 well »Geotehnika d.d.« Zagreb, used percussion drilling method to construct it. Owner of the water well MB-2, »Hrvatske vode« in a regular bidding, selected »IGH d.d.« as the Contractor to construct MB-2 well. Though this well has been performed by the Subcontractor »Geotehnika d.d.«, nominated jointly by Owner and Contractor. The Consulting Engineer (CE) has been nominated by »IGH d.d.« and confirmed by the Owner of the well too.

The experience gained and recorded by CE during construction of this expensive and time consuming well, may help to avoid some future problems in drilling operations, and save money for the Owner, Contractor, and in particular for the Subcontractor. This paper deals with reasons of a very low progress of operation using percussion and rotary drilling methods.

Drilling prognosis and design of well

Well design is the process of specifying the components and dimensions for a well. The principal objectives of good design should insure the highest yield with minimum drawdown consistent with the aquifer capability, long life of well and its reasonable cost, adequate protection of good water quality, including insurance of contaminants-, sand- and turbidity-free water.

The Buško Blato area represents a typical karst environment with highly developed karst features (Fig. 1) where hydrogeological characteristics are connected with carbonate rocks and their structural elements (fissures, faults and folds) as a result of tectonic disturbances (Nikolić, 1972). Both wells are located in a typical karst features vrtača.

Drilling prognosis is the plan by which to drill a well, and if appropriate, it is a »bible on location« for the Consultants (Davenport, 1992). It covers enough relevant data to select adequate drilling rig including mud pump and drilling tool. Every phase of the operation should be covered in the prognosis, including: location layout, permit for work issued by the relevant authorities, the drilling procedure and practices, bit programme, penetration rate, weight on bit (WOB), revolution per minute (RPM) of drilling tool, mud program, casing and cement program. The bit records and mud service in location of the area show us what bits have been successful in the area you are going to drill.

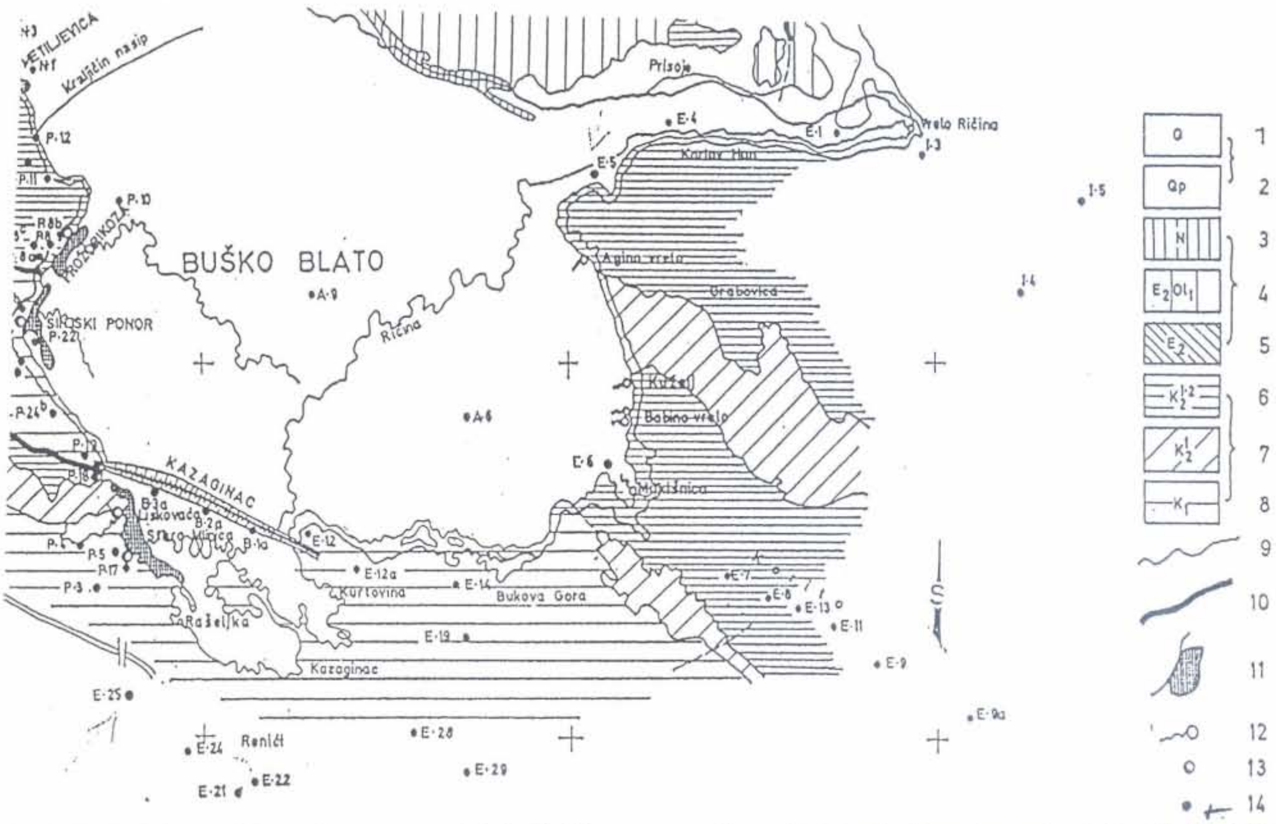

Fig. 1. Geological map of the south-eastern part of the Buško Blato area according to B. Raljević, with exploratory boreholes (Nikolić, 1972)

1 and 2 Quaternary
3, 4 and 5 Tertiary
6, 7 and 8 Cretaceous
9 Normal geological boundary
10 Established fault
11 The ponor zone (developed in the western zone)
12 Spring
13 Ponor
14 Exploratory-piezometric borehole
15 Water wells

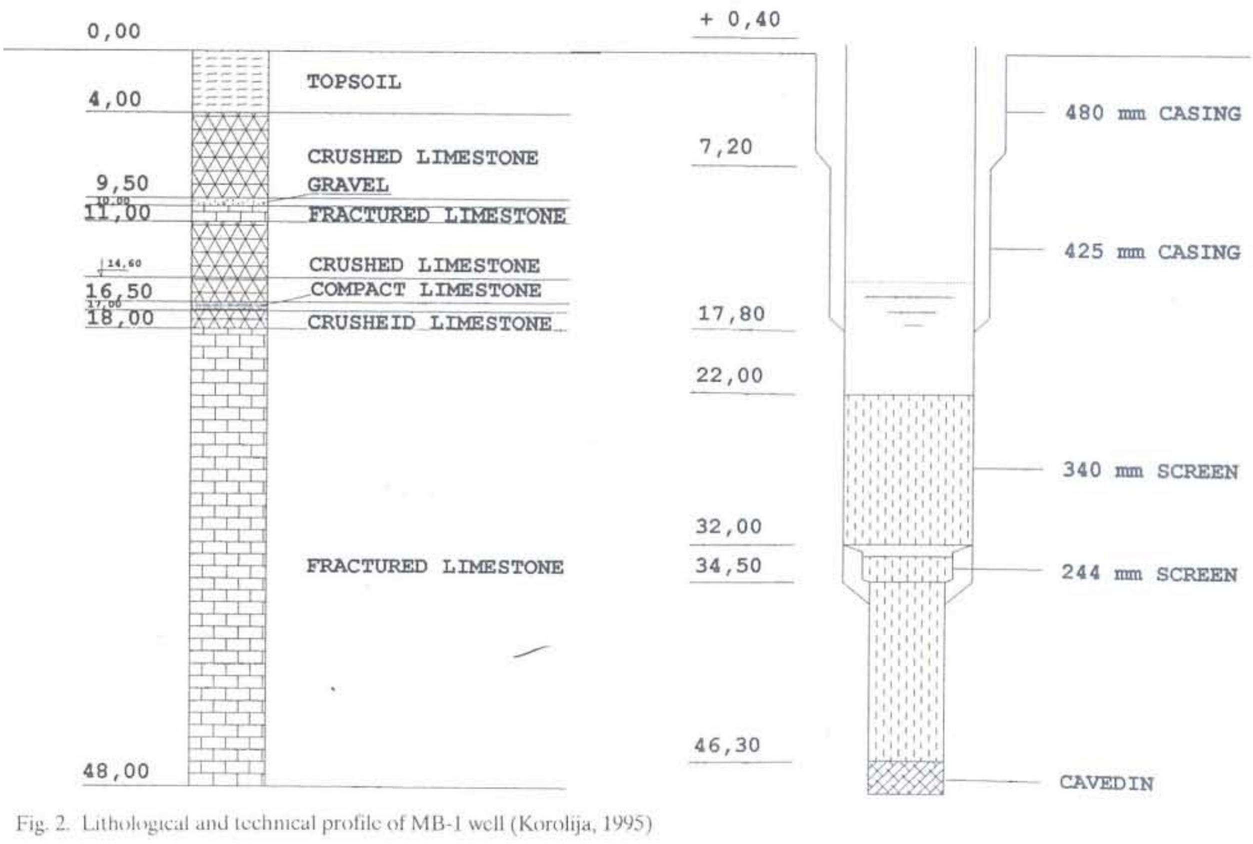

Fig. 2. Lithological and technical profile of MB-1 well (Korolija, 1995)

Geotehnika d.d. constructed the well MB-1 only few months before design of well MB-2 and the negotiation of contract for its accomplishment. Fig. 2 shows the lithologic and technical profile of MB-1 well after Korolija (1995). Construction of well MB-1 took 48 days, three times longer than it was planned. The main reason for low progress was the cable tool drilling tool, which does not suit the drilling in the unstable fractured limestone rocks encountered at location MB-1. The location of MB-2 well was only 4 meters distance from MB-1, but as per »Georadar« profile data, there was expected the stable limestone with fissures, cracks and some caves.

Design of well MB-1 and Contract documents for its implementation prescribe cable tool and the pumping test from the open well 300 mm diameter and 60 m depth. Only the shallow interval (15 m) of this well had to be drilled using drilling bit 400 mm diameter, and cased with 340 mm diameter conductor casing, cemented in this interval. Pumping test has been accomplished from a 46.30 m deep well with installed screen (220 mm diameter, Fig. 2).

After regular bidding, »Hrvatske vode« as owner, selected »IGH d.d.« as the Contractor to construct MB-2 well, but owner and contractor, have assigned jointly »Geotehnika d.d.« as the Subcontractor to implement this well, setting a casing up to 18 m depth, and using rotary drilling method with conventional circulation of water in interval from 18 to 86 m.

After study of implementation records and documents get through the process of construction of well MB-1 using the cable tool drilling method, the selected Contractor »IGH d.d.« sent the Notice to Subcontractor with the technical profile of the well MB-2 (Fig. 3) and special conditions as follows:

1. Subcontractor have to use rotary method of drilling,
2. Well diameter should be minimum 508 mm (20"),
3. Drilling depth of the well is 86 m (from +716 to +630 m altitude),
4. Pumping test should be performed with observations of groundwater level at +640 and +685 m altitudes,
5. Pump the water at a maximal rate of 110 l/s,
6. Pump the water in open hole,
7. Isolate the shallow 20 m of well, between altitudes from +716 to +696 m,
8. Stainless steel casing and screen should be installed,
9. Water sample should be collected from altitudes +640 and +685 m during the pumping test and analyzed in a certified laboratory,
10. Construction of well should commence before 25 August 1996,
11. Pumping test should be performed during the period between 15 and 20 September 1996.

Fig. 3 shows the designed depth of the well, disposition, diameter and total length of screen having an average open area 30 per cent. For a standard slot velocity of 0.03 m/s (Waltan, 1975), and desired discharge (pumping rate in point 5) of 110 l/s, the total slot area is more than double than required. The reduction of the total slot area through reduction of the screen diameter and the diameter of drilling and casing is a good opportunity to reduce the well cost and increase the economy of penetration rates (Table 1).

Very little of drilling practices has been stated in the Notice to the Subcontractor. The successful drilling progress require an adequate bit program, weight on bit (WOB), revolution per minute (RPM) of drilling tools, torque, and the prognosis of penetration rate. Well-logging procedure, isolation of deep and shallow aquifer zones (point 9), cementation of conductor pipe (point 7) etc. are also missing.

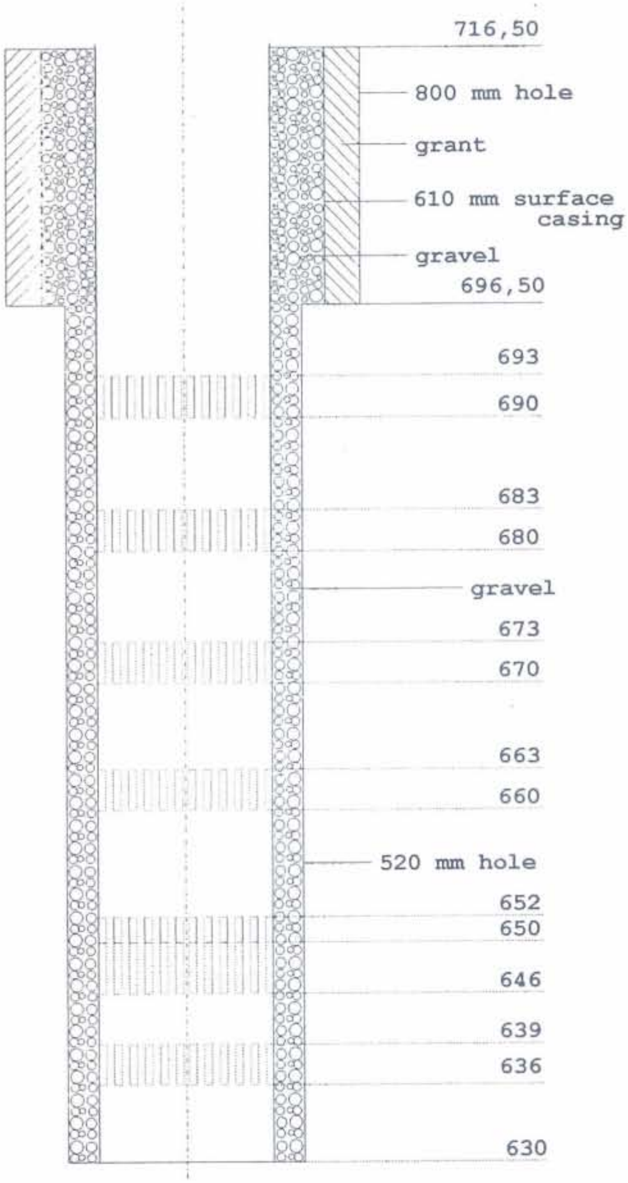

Fig. 3. Disposition and dimensions of casing and screen (IGH d.d., 1996)

The hardship in implementation of the well MB-2 could illustrate the fact that the best equipped drilling company in Croatia did not compete for this job, though they had a free crew, many drilling rigs, enough tool and the necessary equipment.

In the discussion among operator's professionals, Contractor and Subcontractor during the contract negotiation, they agreed to use only water provided from the MB-1 well in conventional circulating direction and avoid any use of bentonite in the system during construction of the MB-2 well. There was no written requirement related to type of flow nor the prognosis of the possibility of circulation loss, etc.

A standard form of the Agreements among the Owner of the water well, Contractor and Subcontractor should clearly define the relevant obligations related completion and payment of the designed well in agreed terms, quantity and quality of operations. The Agreement should include all Contract documents consist of all necessary prognosis, condition and specification, technical provisions with drawings and plans including the modifications and Change Orders (USEPA, 1977). International Drilling Contractors (IADC) provided their special form of drilling contracts for construction of deep wells for investigation and production of petrol and earth gas. IAD contracts could have three forms: a) Daywork contract, b) Metrage contract and c) International daywork contract (Davenport, 1992).

Contract documents for the implementation of the MB-2 well does not comprehend the provision of any »logging the hole« with electrical, nuclear, TV, nor by collecting of core samples. CE has given point to the purpose of logging in order to determine the basic hydrogeologic characteristics of various intervals of the well and schedule the appropriate disposition of screens. The Owner and the Contractor took in consideration this issue to decide about it later. Anyhow, CE advised to OE to observe and register all hydrogeological and geotechnical changes on the site during the construction of the MB-2 well and the nearby piezometer.

Plan of drilling operation

It was expected that the drilling procedure was analyzed and all operations planned accordingly and noted down in the Contract documents because Geotehnika d.d. used to have the best reputation in business of designing and drilling of water wells in Croatia.

Since the upper layers are unconsolidated fractured limestone mixed with clay and terra-rossa, the plan had foreseen installation of conductor casing 625 mm diameter and perform the cementation in order to prevent caving in and percolation of surface water into annular space. Further drilling was expected in the stable fissured limestones which led to the decision to apply conventional direct circulation drilling method. The Subcontractor was optimistic in view of success and the penetration rate using rotary drilling rig. This optimism excludes CEs idea to use Down Hole Hammer, or the rotary drilling with reverse circulation (Table 1).

The field crew staff have good knowledge of the possibility of circulation loss (no return of cuttings outside the well) and cave-ins in the bottom of the MB-2 well during drilling operations. They had in mind the use of Air lift pumping to remove the cuttings and cave-ins from the bottom. The consumed fuel and time of crew and other expenses would be on the cost of Subcontractor, because they have signed the »Metrage contract«.

The article 5 of the Contract between IGH d.d. and Geotehnika d.d. prescribed 45 days for completion of the well as shown in Fig. 3, including pumping test. Work plan with time-table of the construction of the well has not been shown although CE has requested it from the Subcontractor and IGH d.d. The first version of the work plan was outlined at the meeting held on 12 November 1996. After many interventions, the Subcontractor sent an additional official document to IGH d.d. on 10 February showing that the MB-2 well will be completed on 28 February 1997, but the well was accomplished 5 months later.

CE was keen to construct two or three wells of smaller diameter in few weeks only, using Down The Hole Hammer (DTH) or the rotary reverse circulating drilling method with adequate rock drilling standard tool, but it was out of question. The Owner, Contractor and Subcontractor appreciate this proposal, but no one had reason to input additional money for investment in special equipment needful for this, only one well, or to reduce the well diameter.

Reasons for low progress in drilling

Two different drilling methods using two dissimilar heavy equipments, both are expensive to transport, use and maintain in the field. The first 18 m has been drilled using special, 800 mm diameter double wall casing, steered by a hydraulic equipment. Excavation and removing of cuttings from the bottom of the well using the Crane »Link Belt« with special clamshell bucket, made feasible the penetration of casing. Excavation of limestone was difficult by bucket, but special chisel (percussion tool) was here of great help to crush the rocks in the bottom of the well.

Drilling of the first 18 m of the well took 6 days. The settling and dismantling of equipment, and installation of 18.5 m casing 658 mm diameter took additional 6 days. The average progress in drilling operation days was only 3 m/day. Mobilization and transport of this heavy equipment was expensive and prolonged the time spent for this relatively small job (Table 1).

The rotary drilling rig with equipment reached the site in Mukišnica on 8 October 1996, and the crew started drilling using three cone Rock-bit IADC code 131 (milled Theet) 444.5 mm (17–1/2") diameter, after 17 days of preparation. The penetration rate with 17–1/2" drilling bit was less than 1 m/day, because the total weight on the bit (WOB) was approximately 1.7 Ton. The Rock-bit was replaced after 4 days of use and total penetration of only 5.80 m (16.40 to 22.20 m). Drilling operation continued with a three cone insert-bit IADC 635 and an additional drill collar (1.5 ton). During the next 6 working days (one working day is approximately 10 hours), the total penetration was 33.20 m; the rate was more than 5.5 m/day. In the interval from 22.20 to 55.40 m 1.600 l/min of water was lost together with cuttings.

The sediments appeared on the bottom during the process of drilling of the well interval from 55.40 to 86.0. The bit kept back 8 days on the bottom of the well to drill 29 m, but the removing of cuttings from the bottom using airlift, took more than 11 days. In addition to sediments, more than 18 days of unproductive time was spent due to maintenance of the compressor and failure on other equipment at site.

Since the power of the applied drilling rig was not sufficient to drill the full size hole 508 mm or 559 mm diameter at one pass, a pilot type of reamer has been adopted to enlarge the pilot hole 444.5 mm (17–1/2") diameter. Drilling string used to enlarge the pilot hole on 540 mm diameter there consisted of drilling pipes 4–1/2" IF, drill collars 200 mm diameter, two three wing stabilizers, and hole opener – three insert-bit cones welded round a collar and guided by a three cone mild steel bit 444.5 mm.

The enlargement of 68 m (18 to 86 m) of the well took 11 days for reaming, 12 days for the removal of settled cuttings using airlift, and 30 additional days for services of equipment and stoppages due to various reasons. An effective development of well took place during the cleaning of drilling cuttings using airlift. The pumping test in the MB-2 well was accomplished in the middle of June 1997 using submersible pump 150 l/s with observation of groundwater drawdown in both wells, lake, and 5 piezometer. The results of pumping test have been reported (Bagarić, 1997, and Zelenika, 1997).

Table 1. Cost of construction of well MB-2 using six different mode of drilling

	Drilling using Cable tool	Driven well	Rotary		DTH tool, BH 181	DTH tool, BH 121
			conv. circ.	reverse circ.		
Depth of well (m)	48	18	68	85	85	2x85m
Consumed time (days)	126	16	70	30	20	18
Total income (kn)	123,000	98,000	260,000	358,000	358,000	358,000*
Total cost (kn)	750,247	147,399	718,453	274,064	179,424	139,000
Difference of Income and Cost (kn)	–537,247	–49,399	–458,453	83,936	178,576	218,934
Average progress (m/day)	0.4	1.1	1.0	2.8	4.3	9.4
Average cost (kn/m)	15,630	8,189	10,565	3,224	2,111	818

* Income is the value of invoices charged the Owner of the well by Contractor.

Mobilization, overhauling and moving of this drilling rig with its heavy tool, pump for water supply, mud tank, welding plant, trailer etc. required prolongation of time and high cost for this only 68 meters of well (18–86 m).

The Owner and the Contractor on the suggestions of CE and OE have taken positive decision and hired an excellent Electric-logging crew with equipment »Crosko d.d.« Zagreb to record: Electrolog, Caliper log, Mudlog, Temperature log, Gamma Ray log, Continuous Directional Survey, and Dual laterolog. Their experts provided the Owner with a very useful interpretation of the results. A special TV camera (Vodovod Osijek) has also been hired to observe the bore hole before and after reaming of the well MB–2. These data were the base to make the final positioning of the screens and their installation in the well in July 1997.

Drilling cost of well

Every increase in drilling costs decreases the job opportunities for drilling organizations, because their clients will seek some method other than drilling in order to achieve sufficient benefits (ADITC Lmt., 1985). Drilling cost of a well relate to consumed time of drilling crew, depreciation of equipment and consumed material during drilling, pumping test, and installation process, particularly of well screen, casing and pump. In any case OE should prepare cost estimates for each method of drilling through analyses of items as follows:

1. Cost of drilling operations (kuna/day) consists of:
1.1. Plant and equipment hire or amortization,
1.2. Drilling crew wages and allowances,
1.3. Fuel, materials, drilling store and bits,
1.4. Major overhauls, maintenance and drillstring replacement,
1.5. Accommodation, travel and hired services,
1.6. Office administration, accounting, purchasing,
1.7. Vehicles and transport, then
1.8. Overhead, publicity, tendering, communication and taxes.
2. Investment in new equipment and depreciation during construction of this well is already included in the cost through line 1.1.
3. Estimation of profit generated on this well using any of available equipment and mutual comparison (Table 1).

The cable tool and rotary method of drilling using conventional direction of water circulation do work the deficit (Table 1) in construction of such a well in the prescribed condition. The highest progress and the most positive difference of the income values (profit) in construction of the well MB-2 is achieved using DTH Bulroc Hyper 121 (2 wells 85 m deep) and Insert-bit (TCI) 444.5 mm diameter, and installed Johnson screen and casing 324 mm diameter (12 inches). The use of DTH tool BH 181 and BB 508 mm diameter, and installed Johnson screen and casing 406 mm diameter (20 inches), is also profitable.

In rotary drilling with direct circulation, the viscosity and uphole velocity of the drilling fluid are the controlling factors in removing cuttings effectively. Due to limitations of pump capacity in large diameter wells with loss of circulation (MB-2) the cuttings cannot be removed efficiently, the rate penetration by direct rotary method of drilling becomes less satisfactory. Direct rotary drilling is highly cost effective in soft and medium low abrasive formation in wells having circulation of water and enough depth to use the required length of drilling collars.

Low progress and high cost in use of percussion method (see Table 1) is due to an abundance of groundwater in the well, caving of fractured pieces of formation to the bottom of well, and disregard of the investment in a more appropriate drilling tool.

To overcome the limitation of hole diameter and drilling rate, the use of rotary drilling equipment with reverse circulation using air-lift were suggested. The air-lift has been used to remove cuttings from the MB-2 well bottom in the interval deeper than 55 m. The continuous use of reverse rotary rig instead of direct rotary equipment would increase rate of penetration and profit (Table 1).

DTH hammers do not require the powerful down thrust and torque of the rotary rig and therefore, it can be used on lighter, less expensive and more mobile machines. The low torque and thrust required by the DTH hammer means that rotation head vibration is appreciably less than that created by the rotary method. DTH offers longer bit life and faster penetration rates in medium to hard rock at any depth.

Particular mathematical models have been introduced to select the optimal solution to construct a water well including the selection of the appropriate drilling mode, rig and tool (Zelenika, 1994). This model was applied to get results shown in Table 1 using data provided in the field and discussions with colleagues in »Geotehnika d.d.« (gentlemens J. Radas, L. Ivaniš and J. Pozaić) and »Dural Trade« Zagreb (gentlemens A. Raić and N. Hadžiomerspahić).

Conclusions

Many groundwater aquifers in Croatia are well explored and developed, but there have not yet been a manual with standard specification of water well, nor any published procedure for an efficient bidding and/or contracting for the implementation of wells. A professional group should prepare and propose as soon as possible a relevant standard specification for design of water wells in different environment to the National Agency for Water Management. All owners of water wells, designers, consultants and contractors should obey such standards in Croatia.

The Buško Blato area represents a typical karst environment with highly developed karst features where a single well of big diameter is not easy to construct with a universal rotary or percussion drilling rig. The cost, possible progress and risk of each suitable choice of drilling equipment should be analyzed in detail before the final decision of use. The data related to comparison of analyzed drilling methods could be seen in Table 1.

Great experience has been gained during construction of the MB-1 well using percussion, and the MB-2 using Drive casing up to 18 m depth, rotary drilling with direct circulation of water up to 55 m depth of well, and combination of rotary drilling tool with use of airlift (reverse circulation) in the interval deeper than 55 m of well. The data given in Table 1 show that the DTH hammer tool is the most rational, because it does not require the powerful down thrust and torque of the rotary rig and it can, therefore, be used on lighter, less expensive and more mobile machines.

The use of rotary drilling rig, an appropriate drilling tool, and reverse circulation of water and air as the drilling fluid would ensure better progress. The reverse circulation of water and air was adopted to remove cuttings from an interval deeper than 55 m of the MB-2 well in use of the conventional rotary drilling tool. The continuous use of reverse rotary rig in place of direct rotary equipment would increase the rate of penetration and reduce construction cost (Table 1).

During the analyses, particular mathematical models should be applied to select an optimal solution to construct a water well including the selection of the appropriate drilling mode, rig and tool.

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