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RISK MITIGATION AND RELIABILTY LESSONS LEARNED FROM IRAQ

Bart Kemper, P.E.
Kemper Engineering Services, LLC

ABSTRACT

The engineering challenges in developing nations can be significant. This is far more the case in a non-permissive environment. The reliability of infrastructure systems can be compromised not only by direct effects of conflict, but the turnover in personnel and lack of documentation. Risk mitigation, particularly in security matters, can easily but unintentionally be compromised due to materials, construction and fabrication, lack of documentation, and making "reasonable" assumptions based on professional experience in more developed regions. This paper will examine key lessons learned in Iraq.

INTRODUCTION

Engineering begins with "recognition of the need" and "definition of the problem." (1) In addition to specifying the things known or needed you also specify the assumptions required to solve the problem. If you change your assumptions you may arrive at a different solution. If you change your assumptions and fail to solve for the new solutions, the solution may fail. This may seem to be intuitive, but failing to recognize what are valid assumptions has been a root cause for design and construction failure when engineers fail to adjust to a new culture or environment. While gravity is a constant 9.8 m/sec^2 is a valid engineering assumption worldwide, the available strength of concrete or quality of weldment is not.

NOMENCLATURE

"Non permissive environment." A state of combat or civil unrest in which routine tasks may require additional security concerns.

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In defining the problem, all assumptions should be challenged, particularly in an new environment. Environmental factors have to be considered. Whereas there is considerable published data on design factors such as wind speeds, snow fall, and seismic concerns within North America and Europe, it may be more challenging to find similar design data in other regions.

Similarly, there are few sources for design factors and considerations for hostile intent, including sabotage or terrorist attacks. Some countries have developed a few systematic design approaches for non-military protective designs, such as the United Kingdom in response to decades of terrorist attacks. There are military engineering references that consider these issues, but most only address field fortifications and temporary expeditionary structures, usually still assuming considerable risk compared to normal civilian levels of protection. Designing for hostile intent is still largely an ad-hoc approach with the required information not readily available compared to fire, wind, seismic, and snow considerations. (2)

It must be understood the majority of engineering done in Iraq has been extraordinary, given the conditions. This paper addresses observed trends and shortfalls. Understanding how engineering errors occur makes it easier to identify and eliminate these errors for future efforts. When we understand both the positive and negative aspects of shortcomings and failures in engineering design, the process itself can become more understandable, reliable, and productive. Since human error is incontrovertibly a major cause of engineering failures, understanding how error-prone situations can be identified can reduce error. (3) Many of the shortcomings investigated were obvious to those who practice in the specific technical area in question. However, it must be kept in the context that the grand majority of engineering was done successfully despite the climate and non-permissive environment.

Working in a developing country introduces a new level of assumptions, particularly with projects with multi-discipline issues. The lessons learned from a year's work in Iraq highlights many of these issues as well as some combat-specific challenges. Understanding these lessons can prepare other engineers for not only working in a combat zone, but in any new environment. While many of the lessons learned are Iraq-specific, such as how a cultural identity can be tied to engineering, the lesson to be learned is not "how to work in Iraq," but rather "how to understand and operate within the local environment and culture."

Historical Background

Iraq has some of the oldest recorded histories. One of the first pyramids, the Temple of Ur of biblical fame, is located in southern Iraq. The Hanging Gardens of Babylon was one of the Seven Wonders of the Ancient World. The Code of Hammurabi is cited by many as not only being one of the founding legal codes for Western civilization, it also contained the first engineering, product, and building code. For example, it specified that if someone built a home for another which failed, whatever damage occurred would be inflicted on the builder, up to and including if the owner of the house was killed, the builder was in turn executed. (4)

Some of these ancient aspects are still seen today. In addition to the many historical sites, the location of most major cities are the same as they have been for millennia. The crisscrossing networks of canals that mark many of the major towns and cities, to include Baghdad, are a millennia-old engineering feature. The "mud wall" construction used in many of the rural areas may be unchanged from the time of the European Dark Ages, but it is unchanged because it works.

The significance of this history is several fold. First, the local population is very aware of their own history. If foreigners are perceived to look down upon the locals or their history it is an affront that can affect all subsequent relations and business dealings.

Second, the locals know what has traditionally worked. Roads, for example, do not need the same design depth as is typically used in the US or Europe due to the lack of ground water and freeze/thaw cycles in most areas. They know where water is traditionally potable or is too "sour" due to sulfur in the water. Some of the non-potable water is so full of minerals it shouldn't be used for industrial purposes. Weather often precludes certain types of construction at different times of the years. This data may be available from those that precede you if your organization rotates its personnel. However, there is no guarantee the individuals who preceded you knew to gather that information.

A variety of structural and equipment failures can be traced back to the foreign engineer not understanding the local soils, materials, or other conditions. Similar projects done years previously using local techniques did not demonstrate such failures. Given that timely use of local knowledge could have prevented these failures, either the foreign engineer was not informed of local conditions or had ignored the input from local sources.

Local engineers are the best source for this data. However, while non-technical people may not be able to couch their knowledge in technical terms, they will often know the needed answers if asked the right question. For example, if there is a site that appears on the map to be excellent for housing or an industrial site and its not used, there is probably a very good reason for it. Several Coalition bases and projects were sited without local assistant on areas prone to flooding, had archeological significance, or had man-made hazards. It is best to have multiple sources for local expertise as expertise and experience varies.

Recent history is also important. In Iraq, the peak construction in terms of quality and good engineering practice was the last half of the 1980's. Much of the planning and construction was done by then-Eastern Bloc countries such as the former Yugoslavia and Czechoslovakia as well as Chinese and French firms. Knowing who provided the engineering and equipment for given site is important when trying to determine what infrastructure is already in place. In many cases the local engineers removed some or all of the documentation for safeguarding, to include plans and manuals. Developing the positive, cooperative peer-to-peer relationship established the trust between Coalition and Iraqi engineers such that the required information became available.

However, the bulk of the construction and engineering done after the first Gulf War was often substandard and focused on either presenting a certain image or taking care of those groups in the government's favor. This is why buildings made even in the 1960's are still serviceable whereas newer buildings are crumbling behind their facades. This extends to municipal infrastructure and industrial sites. In most countries the political environment influences what moneys and resources are available for a given sector of society. Understanding the current affairs and recent history provides insight into what engineering assumptions are reasonable and which ones need considerable data to confirm.

Finally, good will is key for an outsider working anywhere, but particularly in an area with limited law and order. While Iraq has the headlines, it is far from the only region where terrorists, insurgents, or money-oriented criminals have to be factored into a project scope just as the terrain and weather is. The title "engineer" commands considerably more respect in many countries, including Iraq, than it does in the U.S.

However, local and foreign engineers have also been targeted in many countries because they represent growth and change that is counter to a given group's agenda. While a close relationship with locals can have its own dangers, having reliable ties with the local community as well as the Coalition and Iraqi police can enhance survival as well as the overall ability to plan and coordinate a project to a successful completion.

<u>Materials and Construction</u>

Outside of failure analyses and forensic engineering, materials are often taken for granted. If a certain grade or strength of steel, concrete, or lumber is specified, the material can usually be assumed to be as specified until proven otherwise. Minimum strengths for a given material are generally exceeded and can be used reliably as designed. What is behind that assumption is multiple layers of quality control by the manufacturer as well as on-site contractors, legal liability if the material is defective or not as specified, and a general assumption that the purchasing and inventory process is accurate and reliable. While exotic materials and mixes may need prior coordination before specifying such in a design, the grand majority of engineering materials is assumed to be available.

These assumptions must be challenged in developing nations, and more so in a non-permissive environment. If they are not challenged, then the risks both to project completion as well as local security cannot be accurately assessed. This in turn prevents steps being taken to mitigate the risk. For example, in many places in Iraq concrete has a 30 day compressive strength of 1000-1500 psi (6.8-10.3 MPa) or lower, whereas in typical design practice in North America and Europe the 30 day strength is no lower than 3000 psi (20.7 MPa) and are often as high as 6000 psi (41.4 MPa). This impacts not only civil engineering projects but also setting equipment, providing reliable security barriers, and repairing damaged infrastructure.

For example, "t-walls", similar to temporary concrete barriers used by highway departments, are used to mitigate risks of terrorist attacks by being a barrier against traffic as well as stop small arms rounds and bomb fragments. Even if a large truck runs into a t-wall and knocks it over, the t-wall is designed such that the truck cannot drive over it. However, there have been terrorist attacks in which trucks have smashed through t-walls, defeating the engineering intent of the t-wall barrier. The specified minimum strength for the t-wall concrete is 4500 psi (31.0 MPa.) (5) The barriers had to be substantially weaker than the design specifications for a truck to be able to smash their way through as reported.

There are many reasons for the lower concrete strength. In some places the water is too brackish or sour to develop full strength. The aggregate is usually smooth river rock instead of the crushed gravel normally used. The smooth river rock can fail to fully bond with the cement, essential creating faults in the material in the shape of the rock. This occurs more often when the rock is not washed or graded. Fine coats of dust can completely prevent cement from bonding with the aggregate. Too many large rocks will create voids during a pour. These various faults in the concrete create irregular opportunities for failure. Its not simply a case of the material being lower strength, it can fail prematurely in a catastrophic mode. This has been seen in some of the Saddam-era construction as well as the post-invasion structures.

Fig. 1 Side view of a t-wall. The exposed steel, large round aggregate, and many voids indicate low strength and a high likelihood for failure under load.

Another reason for poor concrete is a lack of quality sand. Despite Iraq being arid in most places, sand is not readily available throughout the country. What appears to be sand in many locations is in fact alluvial silt, dried and ground into a fine gritty dust. While it may feel like sand when dry, when wetted it becomes a plastic clay-like material with limited load bearing capacity. This is not only important for concrete, but also in gauging moving logistics which in turn dictates when items can be available. Asphalt, bitumen, lumber, and crushed gravel are also in short supply locally, requiring the material to be trucked in from out of Iraq for Coalition projects or bought on the black market by local nationals.

These materials must also be tested or assumed to be of minimal quality. Lumber, for example, is often ungraded or straight mill run of unspecified wood, whereas the typical drawings assume structural grade members of a specified wood such as Southern Pine. This is the likely root cause for several failures in which there was no construction fault detected. A simple load test to failure can provide a rough estimate of a given batch's strength. However, greater reliability may be achieved by adjusting designs for the lower quality, such as N3 for soft pine.

Welding is the standard technique for reliably joining steel in many places. However, there is a lack of trained welders, welding equipment, and welding supplies in various locations in Iraq. In many projects welds were often inadequate and fabrication fell behind schedule. However, Iraqi engineers and contractors pointed out they could meet fabrication requirements with bolted instead of welded connections. When designs were modified for bolted connections, jobs were completed on schedule with greater reliability. It is also easier and more readily available to do on-the-spot quality control using a torque gauge for bolted connections than to use dye penetrant or radiological testing of a weld.

Skills and liabilities for a given labor pool had to be evaluated carefully. Even when using Coalition engineer units, skills and equipment could vary considerably from unit to unit. Contract labor within the bases was often more consistent, but quality control had to be enforced to achieve reasonable levels of reliability. However, this labor is typically not available for work outside the bases.

Local Iraqi labor is needed outside the bases and is often used on base. One of the reliability issues is a given individual could be a mason one day, carpenter the next, equipment operator the next, and pipe fitter the following, indicating the work force does not have in-depth experience. Since there are no programs such as “certified ASME welder” in place, the project engineer needs to consider how to conduct quality control/quality assurance. Adjusting designs for a lower skill level, such as larger tolerances or increasing the safety factor, can increase overall reliability.

Another factor is the fact the Anti-Iraqi Forces (AIF) would target anyone working on improving infrastructure, regardless of whether they were working for Coalition forces. Individuals or entire work crews could quit a job with no notice due to death threats. Project managers have to account for these possibilities in their work plans.

A repeated challenge was the personnel cycle that generated the problem identification, funding, and design was often over before construction began. It was up to the next set of personnel to execute the project. Thorough documentation remains critical to military and Coalition-contracted work due to the cyclic nature of the work force.

Finally, there are politics that influence the use of engineering materials. There is a desire to not appear to be “permanent” in most locations. While some applications, such as runways and key roads, require work to a given standard to be safe and reliable, others do not. For example, gravel may be used for a parking lot or secondary road instead of paving materials.

This is not limited to Iraq. In the Balkans it is less expensive to use the locally available bricks than plywood and lumber. Wood construction products are not readily available and must be shipped in. Despite this, wooden structures were used for US training facilities in order to not be seen as having “permanent structures” in order to comply with both U.S. and host nation policies. In cases where “life, health, and safety” dictates the more robust materials must be used, the engineer has to make this clear to the military commander or civilian authority.

Security

Security engineering is a specialized field that combines civil and mechanical engineering to accomplish specific operational goals, ranging from a simple “protect this area” with sandbags and concrete walls to more complicated functions such as an Entry Control Point (ECP.) An ECP may have multiple lanes of civilian, industrial, and military traffic, multiple search sites, complex scanners and video systems, and facilities for personnel searches and badging. At any moment an enemy attack could occur, a military convoy may need rapid passage in or out of the ECP, or emergency response such as fire or ambulance may need to respond. All of this must be covered by guards on the ground and in towers, and the guards must be able to fire their weapons without endangering noncombatants.

While much of the standard practices are “rules of thumb” published in general doctrine, such as “use sandbags to provide six inches of cover,”(6) the actual engineering data and equations are rarely presented just as the complex truss information is typically not published in order to use a bridge. However, security engineering deals with a complex, adaptive design constraint: a person with hostile intent. This can create challenges when the underlying assumptions behind the doctrine and rules of thumb no longer apply because the enemy has changed how he operates. There can’t be a “one size fits all” ECP because the terrain, local needs, and local enemy dictate different solutions.

Local soils play an important part in security engineering for mitigating the threat of small arms and indirect fire such as mortars and rockets. One of the tried and true methods for protecting people and equipment is sandbags. There are many sources within the military that specify the depth of coverage needed to protect from a given threat. However, the underlying assumption is the sandbags are filled with sand.

Different soils have different ballistic properties. The scalar value used for several ballistic equations for sandy soils is 4-6. For loose, silty soils the value is 15-30. (7) The actual stopping power is dependent on the projectile mass, velocity, cross sectional area, "nose" shape, and other factors. For example, for an AK-47 assault rifle firing a 7.62mm bullet, loose silty soil has about 1/5 of the stopping power of sand.

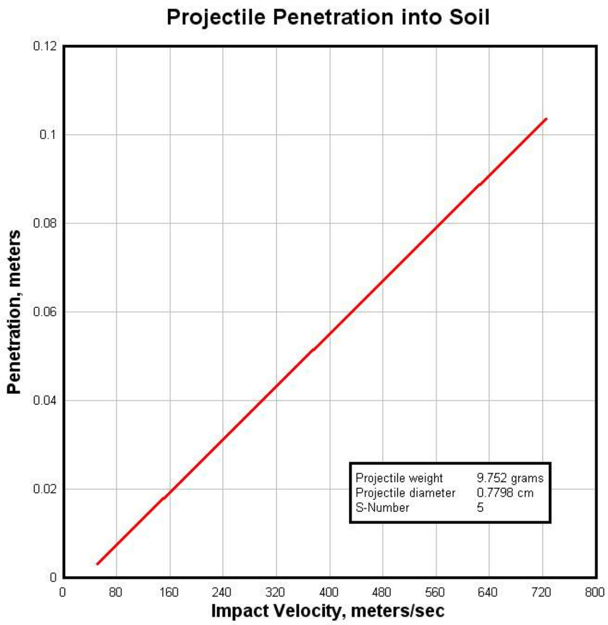

Fig. 2 Penetration vs. impact velocity for a 7.62mm round into sandy soil, the optimal fill for sandbags. Calculations are done using CONWEP.

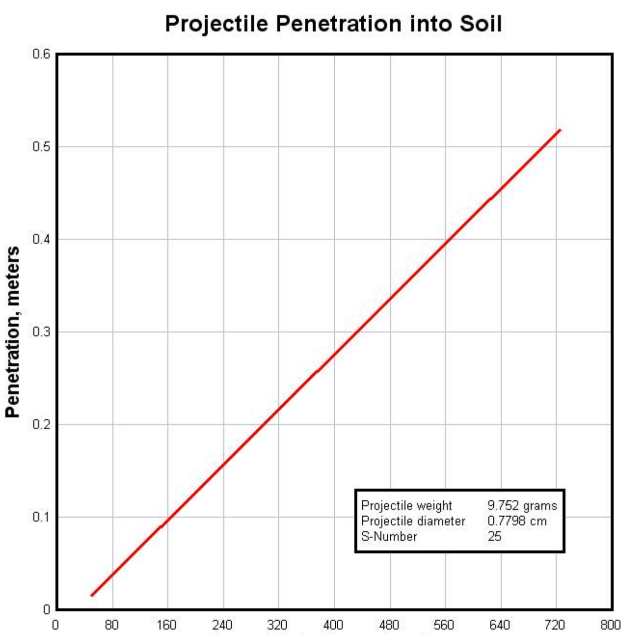

Fig. 3 Penetration vs. impact velocity for a 7.62mm round into loose silty soil. This has approximately a fifth of the stopping ability of sand and directly effects the reliability of protective earthworks designed with sandbags.

Few, if any, field manuals annotate the need for sand vs. soil. If sand is not available, either more sandbags or other forms of protection are needed. Failing to do so results in the users believing their risk is mitigated when it is not. Typically this won't be detected until something catastrophic has occurred.

This has a cascading effect in the logistics of using sandbags for protection. In order to provide the required reliability, there is five times the dead load added to any structure using sandbags for overhead cover or, in the case of towers, deck cover to prevent weapons fire penetrating from below. This also increases the cost, time for construction and logistic requirements. This consequently delays when a given protective structure is functional, which can impact other operations.

Fig. 4 Sandbags lining living quarters. The sandbags are high enough to protect personnel sleeping in their beds and layered thick enough to stop small arms and shell fragments. Sandbags typically deteriorate within 18 months and need to be replaced.

Many standard designs cannot reliably hold that load. This also means you have five times the number of sandbags to purchase and replace every year, as the sandbags tend to deteriorate in Iraq after a year. This is either labor intensive for the troops or a large increase in the cost of using contract labor for protective structures. Failing to perform this maintenance often results in piles of deteriorating sandbags that provide very limited protection. In recognition of this problem HESCO™ Bastions geotextile "baskets" have been used extensively in Iraq to replace sandbags as they can be filled with scoop loaders and have a longer use life than sandbags.

Fig. 5 HESCO™ Bastions used to replace sandbags. The geotextile material lasts longer than the nylon sandbags and are easier to fill while providing the thickness required.

Similarly, the strength of concrete dictates how well it acts as protective barrier. Concrete is not meant as a "close in" protective barrier for explosives. Even if the blast does not rupture the concrete, the shock wave will propagate through the concrete and may "spall", or break off, pieces of concrete as the energy reflects off the back face. Spalling can occur due to blast alone or due to the shock created by high-speed shrapnel impact. The weaker the concrete is, the greater the likelihood the concrete barrier can become secondary debris. (6)

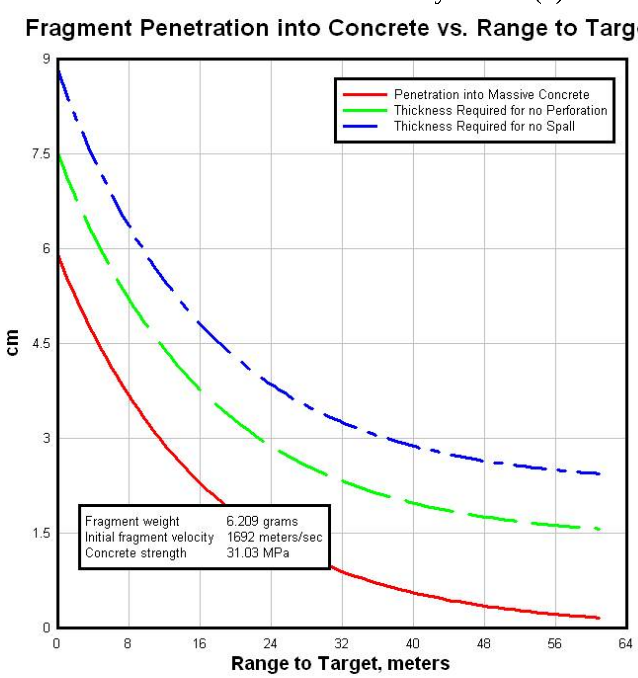

Fig. 6 Fragment penetration of a 120mm mortar shell with 4500 psi (31.03 MPa) concrete. These calculations neglect blast effects. Calculations are done using CONWEP.

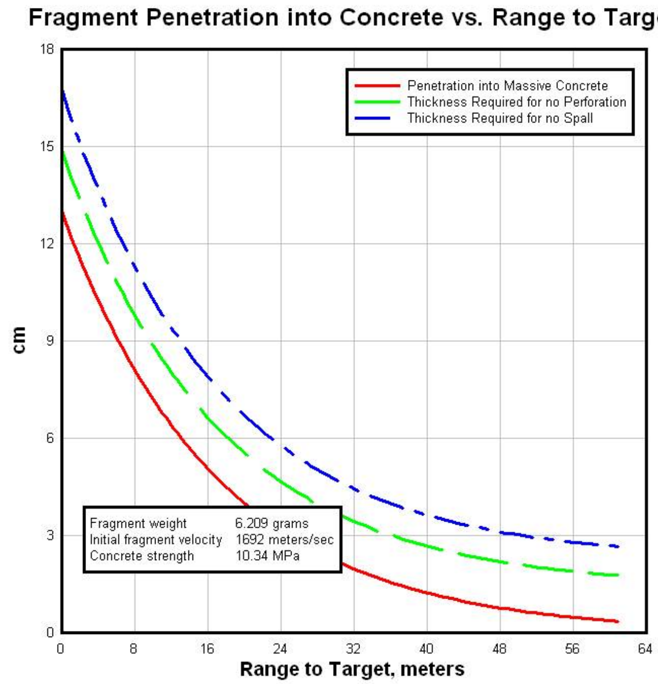

Fig. 7 Fragment penetration of a 120mm mortar shell with 1500 psi (10.34 MPa) concrete. This shows that while common structural thicknesses may be defeated, most protective structures are at least 12 inches (30 cm) thick and will protect against fragments.

Concrete barriers are best used to protect against shrapnel and small arms fire. While blast can be devastating in close proximity, the blast effects diminish with the cube root of the distance. Shrapnel and debris thrown by the explosion tends to travel at a dangerous speed until they hit something that is hard enough to stop them. This is why most artillery rounds are optimized to produce the most shrapnel instead of the largest explosion for a given caliber. Unlike sandbags and geotextile baskets, concrete barriers do not require maintenance or replacement on a regular basis.

Composite barriers of earthworks and concrete structures are preferred for mitigating blast effects compared to earthworks or concrete structures alone. (6) However, structural response to blast is highly nonlinear. In order to design any protective structure the net explosive weight, distance from the barrier, and type of explosive has to be specified. Once this is determined, the structure's orientation to the blast, geometry and composition will determine the structural response. (7) The challenge is the person doing the design must successfully anticipate the enemy, who has the advantage of being able to gauge the system once in place and test it repeatedly.

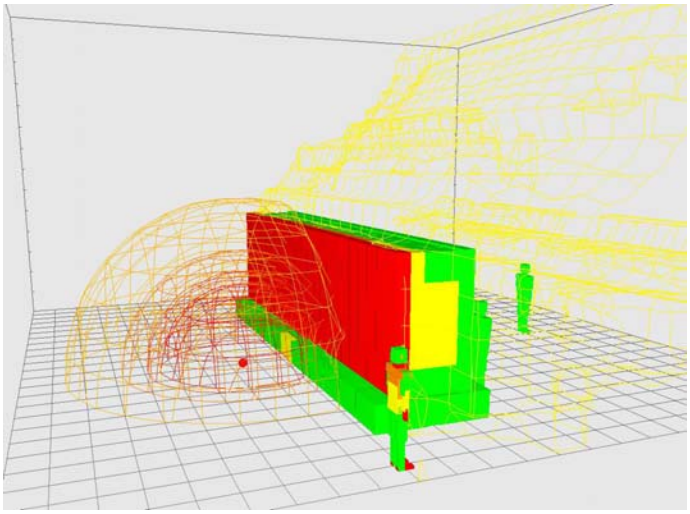

Fig. 8 A blast model showing a composite wall of two t-walls with a larger HESCO™ Bastion between. The t-wall nearest the blast is destroyed but the earthworks absorb the blast and secondary fragments. The farside t-wall remains intact. Blast modeling using HEXDAM.

Any one structure can be defeated. Successful protective design requires a system of defenses, to include plans for response teams and contingencies addressing any given structure being defeated. The risk, such as the range of possible enemy attacks, must be quantified and systematically compared. Just as a successfully designed industrial facility includes operational, maintenance, and emergency considerations, protective systems must include the same. A common cause for system shortfalls is designs done by operationally-oriented personnel without engineering participation. In other situations shortfalls are caused by using "canned" drawings or by engineers not addressing the tactical considerations regarding local terrain, weather, materials, operational response requirements, or enemy considerations. While this is an acceptable practice in a hasty defense situation in order to provide immediate security, it has resulted in significant shortfalls when developing deliberate, longer term defenses. The costs required to change these systems are sometimes prohibitive, requiring commanders or facility mangers to accept greater risk or attempt to mitigate the risk using other means.

Case Study: Pump Station

One example shows how all of these considerations can come into play. A water pumping station on the Tigris supplied both the local community and an air force base now used by the Coalition. The water pipeline was dozens of kilometers long. The Coalition base was not getting sufficient water on base for their daily operations during the hotter weather. While the initial problem definition of "the base needs more water" seems apparent, there were many unknowns regarding the pump station and pipeline.

The lack of water during the hot season was not readily explained. The demands for water on the base did not increase substantially with the heat. The pump station was initially assumed to be the cause, in part because it was run by locals and was relatively remote from the base. The maintenance for the non-military system had been deferred for years due to the population not being favored by the previous regime. Consequently, the locals had tapped the military water line at many points for their own needs. This reduced production to the Coalition base and created some initial friction between the local community and the Coalition.

Over time it was noted the taps enhanced security as the local population now had a vested interest in the pipeline. Local insurgents would not target the pipeline. Foreign terrorists were turned in or attacked by Iraqi forces for targeting the pipeline. While some Coalition personnel advocated eliminating the civilian taps on the water pipeline, it was recognized the taps mitigated security risks by providing good will, better local security, and enhanced the standard of living for the local Iraqis. A different solution was needed to provide water for the base.

The lack of maintenance of the facility, coupled with the pipeline taps, reduced production at the Coalition base. Pumps leaked, pipes had failed, and instrumentation was broken or missing. The flow estimated at the Coalition base was ½ to ¼ of the rated pump capacity, but there was no instrumentation to measure flow or pressure. Linepack for 25 km of pipeline took several hours. The amount of water tapped was estimated to be around 25%. The linepack time and theoretical pumping capacity was not consistent with the estimate water delivery rate and losses. One of the few things known was the amount of water arriving at base was insufficient, which potentially threatened base operations.

The local Coalition base engineer visited the pump station several times. It should be noted that such visits were not a casual affair, but required an armed patrol to take the engineer to the station and provide local security. It's possible insuficient time was budgeted to gather all the needed data. Based on these visits, the engineer specified new pumps to fix the production problem.

However, the entire system was not fully defined. The taps were not accurately accounted for, nor was the design pressure for the pipeline header. The pumps were specified with with higher flow rates and pressures because "more production is better" to compensate for unspecified amount of water taps. The pressure rating on the pipe fittings were not noticed or neglected as the new pump output pressure exceeded the fittings' pressure rating. Similarly, the new power requirements were higher than the existing electrical system capacity. A few civilian contractors on this base had more technical expertise in various areas but were limited to patching symptoms found on the base. Civilian contractors were also frequently not allowed by company policy to work off base.

The specifying engineer finished his tour prior to the pumps being delivered and not all of the required information was passed on to the new engineer. Assistance from engineers on other bases was not sought. The Iraqis had experienced personnel turnovers as well, although not as often as the Coalition engineers. The new engineer assumed the incoming system was properly specified and had it installed per standard practices. Consequently, when the pumps were first put into service they “blew out” many of the civilian taps on the pipeline, unintentionally protecting the pipeline from rupture. The pumps shortly thereafter overloaded the electrical system. The reasons these events occurred were not immediately apparent, given the new system was assumed to be properly designed and specified. Further, the pumps delivered were pulp & paper service pumps, not water pumps, with counterfeit data plates. The actual make and model of the pumps were never fully determined.

The Iraqi engineers shortly thereafter resumed control of the pump station. They choked the flow of the water from the wet well to the pumps to reduce the output. This was a short-term fix to provide reliable water supply to the base. The local engineers requested support from military engineering teams and contractor engineers based elsewhere. This combined effort had civil and mechanical engineers, electrical engineering technicians, and trained drafters to provide a comprehensive solution. The first priority was to reduce the number of assumptions and quantify the pipeline capability by taking dimensions and using flow software to estimate pipeline capacity. This revealed the flow losses were closer to 75%, which was consistent with revised production rates and known linepack time. The next priority was to specify new pumps that were consistent with the original mechanical and electrical specifications.

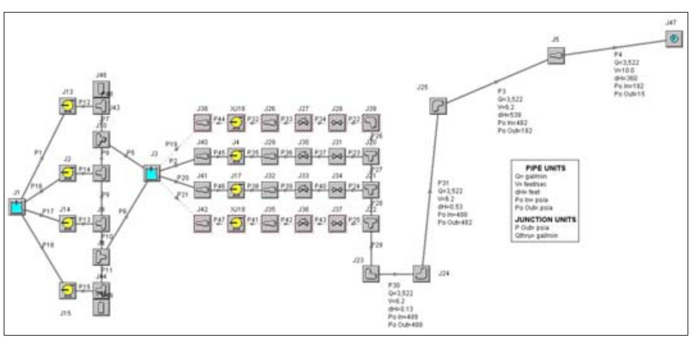

Fig. 9 Flow analysis of the water system, modeling flow from the Tigris to the wetwell to the receiving cistern. The two larger pumps created 490 psi pressure in a system with 300 psi fittings. The model of the original system created 260 psi. Flow modeling using AFT Fathom.

Bolted pipe connections were used whenever possible rather than welded connections. This enhanced fabrication reliability as it was more compatible with the local labor skills. New instrumentation replaced missing gauges and meters, enhancing reliable operations and production. Some of the specifications were determined by Coalition engineers with civilian industrial backgrounds. The remainder was determined from copies of original plant documents one of the Iraqi engineers had found off-site in an Iraqi ministry office.

A combination of an informal survey of the pipeline and discussions with local Iraqi army units and civilian leaders indicated the locals used more water during the summer to do everything ranging from watering their garden to running a carwash business. This explained a large portion of the lack of production on base. The base commander negotiated with local civic leaders to document and control the number and size of the pipeline taps, balancing the local needs with the base’s needs. Local Iraqi Army units enforced the agreements. Earthworks and concrete structures designed for local conditions were used to both limit access to key areas as well as protect from indirect fire.

The end result was a fully quantified system with known equipment operating within design parameters to produce sufficient water for all users. The initial challenges arose due to the previous regime’s intentional neglect. Subsequent challenges were due to rapid turnover in personnel, lack of documentation, and difficulties in working with the local engineers. The most significant failing was not testing assumptions made by others. In failing to fully define the system, the problem was never fully defined. The solution required a comprehensive engineering approach with mechanical, civil, electrical, and military engineering coupled with civil-military oversight. Ad hoc solutions created short-term patches that at best camouflaged root-cause issues and at worst created more severe problem. “Doing something” is not always better than doing nothing.

<u>Lessons learned</u>

1. Good will with the local community is vital. Its is the foundation for not only determining local data for engineering efforts, but also enhances the safety of individuals and projects in a non-permissive environment.

2. Local knowledge is vital. Seek out and cultivate multiple local sources of expertise.

3. Be prepared to do considerable research to quantify the system being investigated. Documentation is often at government agencies or with engineering firms outside of the host nation. Extensive forensic engineering may be needed to define the system.

4. Test all material whenever possible. This includes soils, concrete, metals, and lumber. If the material cannot be verified to meet standards designs suitable for other regions, adjust the design to account for the material or construction techniques more commonly available.

5. Security, logistics, and political considerations can impact engineering project. The engineer must ensure these considerations do not override safe, reliable engineering practice.

6. Become more of a generalist. Engineers have to be able to assess an entire system, to include mechanical, civil, electrical, environmental, controls, and security aspects because of the limited opportunities at a given site. While no one can know all aspects of engineering, developing a broader base of knowledge allows for better on-site assessments and data gathering for later consultations with others with different expertise.

7. Develop multi-discipline teams. In addition to traditional engineering disciplines of mechanical, civil, electrical, and environmental engineering, the team should include those with current military, logistic, and security engineering expertise. Local engineers should be included if at all possible. If the team cannot be assembled physically, then email and telephone calls can be of value. However, whether the individuals have first-hand knowledge of that region and its current conditions should weighed accordingly based on the nature of the project and the expertise required.

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