Concrete Printing

Less is more

by Capt Eric F. Satterthwaite

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As the Marine Corps embraces the concept of expeditionary advance base operations (EABO) as a methodology for enhanced maneuver and battlespace control, it also inherits the problem of solving the engineering challenges of EABO. For consideration, a problem statement for EABO engineering is: How does the Marine Corps ensure mobility, countermobility, survivability, and general engineering (Marine Corps engineering functions) across a widely distributed expeditionary environment while reducing logistical requirements? Future Marine Corps engineers will be called upon to create increasingly complex projects with smaller teams and less access to raw materials; they will be asked to create more with less. Therefore, future Marine Corps engineers will need equipment comparable to the challenges they must overcome.

Considering the problem statement, the equipment of the future engineer must provide certain capabilities. It must be versatile, enabling innovation to solve problem sets since the future engineer will not have access to a warehouse of specialized tools. It must require few inputs, since the future engineer will have reduced access to refined materials and be more reliant on those locally available. It must reduce the number of Marines needed to complete complex projects, since the future engineer will deploy in smaller teams. Finally, it should have a design aspect, because the future engineer will need to be able develop and implement solutions to unique problems.

One equipment solution that incorporates the equipment characteristics previously described is the employment of 3D concrete printing. The Marine Corps, in coordination with the United States Army Corps of Engineers (USACE), is currently experimenting with this technology and has successfully completed two significant projects of note. The first project was a barracks hut, and the second was a concrete footbridge. The barracks hut was completed in approximately 72 hours, constructed with a team of 12 Marines and 4 additional USACE engineers. Construction used six inputs: sand, gravel, cement, water, dry admixture (admix), and wet admix. Admixes are chemical or material components that are added to the base concrete to achieve specific material characteristics. The rippled wall designs make the walls self-supporting, and the hut boasts an approximate floor space of 30 feet by 16 feet. This is an example of using 3D concrete printing technology for general engineering and survivability purposes. The footbridge was completed in six days, which included construction, curing, transportation, and emplacement. The construction team was comprised of seven Marines, four USACE engineers, and eight Seabees, and the bridge was preliminarily designed by Marines and then reviewed by USACE engineers for safety. It used eight inputs: sand, gravel, cement, water, dry admix, wet admix, fiber reinforcement, and rebar. The bridge spans a 32-foot-wide

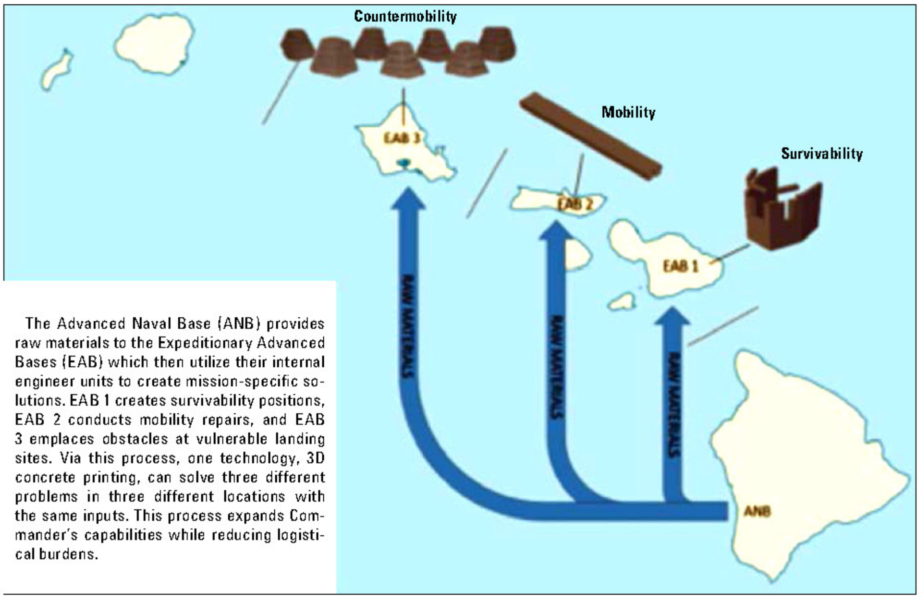
7th Engineer Support Battalion constructed a concrete bunker during a 3D concrete printing exercise in 2019. (Photo by Maj Kenneth Kunze.)

gap and has a calculated load capacity of 3,500 pounds, or a military load capacity (MLC) of two. After testing, it was determined that the bridge could bear a dynamic load of approximately 38,000 pounds, which translates to being able to safely bear the weight of an up-armored HMMWV, a joint light tactical vehicle, or an unloaded Mk23 MTVR. The footbridge is an example of using 3D concrete printing technology for mobility purposes.

These two projects illustrate how 3D concrete printing technology accomplishes each of the requirements for future engineer equipment outlined earlier. First, versatility: without any modification, the same piece of equipment was able to construct two completely different projects across various functions of Marine Corps engineering. Second, both projects were completed without the use of forms, the current leading technique for large-scale concrete construction. In doing so, these projects removed the need for wood, nails, screws, form designs, and time associated with making forms. With both projects using less than ten inputs, and with sand, gravel, cement, and water being widely available raw materials around the world, 3D concrete printing effectively reduces the amount of required inputs over traditional concrete construction methods. Third, these projects produced items that would normally be assigned at minimum to a squad (thirteen Marines). Because of the experimental nature of these projects, additional personnel were utilized (USACE engineers and Seabees); however, both projects used less than a squad of Marines. With further development, this technology could easily be operated by seven or eight Marines. Finally, the concrete footbridge illustrated that by using 3D concrete printing, Marines can custom design operationally relevant structures without having to rely upon assistance from Army or Air Force units.

Acknowledging the argument that 3D concrete printing seems like a viable candidate for future employment by Marine Corps engineers, it is necessary to highlight what a fleet-ready version of this technology would look like. In its current state, the printer is undergoing research and development to further improve the technology. First, the fleet-ready version of this technology should come with a control computer preloaded with structurally approved designs. For example, the control computer could come with designs and instructions for an MLC70 vehicle bridge. Because of the complex nature of an MLC 70 bridge and implications of the end use of said bridge, Marine engineers should not attempt to design a bridge of that magnitude in the field. Instead, preapproved designs (bridges, culverts, runways, fighting positions, barracks huts, obstacles, etc.) would come preloaded to alleviate the burden on operators and ensure that those designs perform as intended. Second, less than a squad of Marines should be able to operate the fleet-ready version of this technology. Third, it should be able to process unrefined raw materials with as few additives as possible. Fourth, it should be able to utilize widely accepted design programs (computer-aided design, (CAD) CAD drawings) for custom projects. Finally, it must be transportable via standard military equipment (palletized, quadcons, ISO containers, etc.).

Once a fleet-ready version is available, how would it be employed? Because of the versatility of the technology, employment considerations may be different for combat operations versus humanitarian aid and disaster relief operations. Combat employment of the technology would leverage EABO concepts to enable a mission-specific production capability within the battlespace. By distributing 3D concrete printers throughout the battlespace, each expeditionary advanced base could produce mission-specific construction projects while logistical support focuses on providing the same raw materials. In essence, this expands the local commander's capability while also reducing and simplifying logistical requirements. (See Figure 1 for a depiction of this employment technique.)



The Advanced Naval Base (ANB) provides raw materials to the Expeditionary Advanced Bases (EAB) which then utilize their internal engineer units to create mission-specific solutions. EAB 1 creates survivability positions, EAB 2 conducts mobility repairs, and EAB 3 emplaces obstacles at vulnerable landing sites. Via this process, one technology, 3D concrete printing, can solve three different problems in three different locations with the same inputs. This process expands Commander's capabilities while reducing logistical burdens.

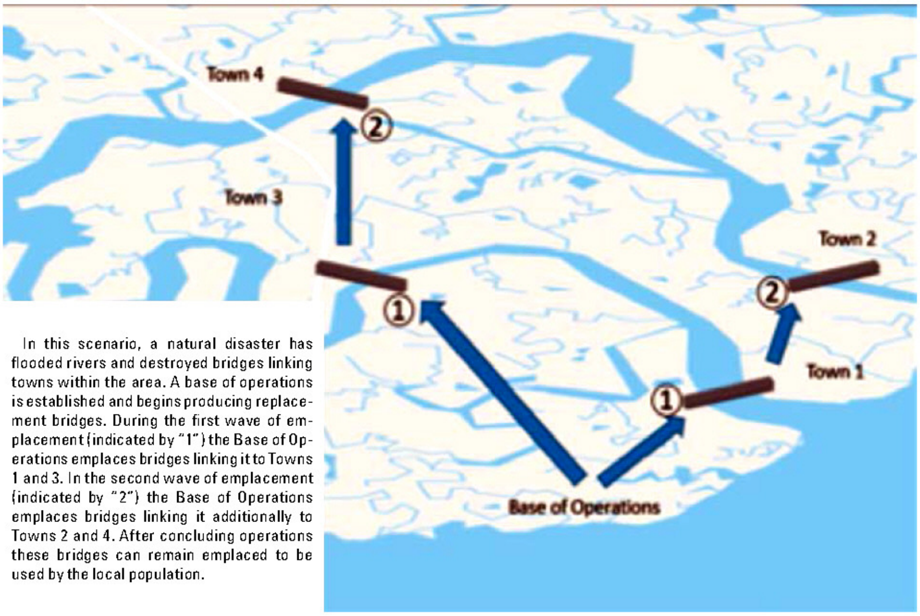
Figure 1. Combat employment of 3D concrete. *(Figure provided by author.)*

Conversely, humanitarian assistance and disaster relief employment of this technology would likely work differently. The employment concept would be mass production at a singular, controlled site and then moving finished projects into place, allowing for tighter control of limited resources and a progressive approach to relief operations. Finished projects could remain emplaced after Marine forces retrograde for future use by local populations. (See Figure 2 on next page for a depiction of this employment technique.)

Now, with an understanding of the employment techniques for this technology, how does 3D concrete printing compete with or outperform our current construction methods? The first distinct benefit is an iterative design process that leverages the capabilities associated with CAD. As an example, see Table 1 on the next page for the design processes utilizing existing methods versus 3D printing CAD.

Using Table 1 as an example, the iterative design process inherent to 3D concrete printing has a distinct time advantage over traditional means. By removing the need to design, create, and remove forms from each step, Marines will be able to rapidly improve designs to rectify identified deficiencies. Also, removing the need to design forms is key in streamlining the process since form design is a highly detailed and technical process. By comparison, 1361 Engineer Assistant Marines are proficient in CAD design work and can produce geometrically complex designs rapidly.

The second distinct benefit is a productivity advantage. By leveraging 3D printing technology, Marines would be able to create more outputs with less inputs, thereby increasing productivity by freeing up resources for other tasks. As an example, Table 2 (see page 55) is a conceptual equipment and material comparison between traditional construction methods and 3D printing. The resource estimates are based on the construction required to create the concrete bridge that was produced in December 2018.



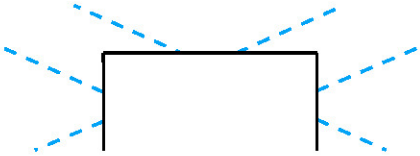
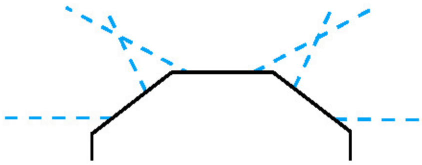
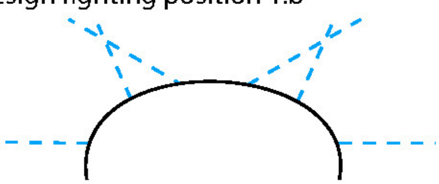
In this scenario, a natural disaster has flooded rivers and destroyed bridges linking towns within the area. A base of operations is established and begins producing replacement bridges. During the first wave of emplacement (indicated by "1") the Base of Operations emplaces bridges linking it to Towns 1 and 3. In the second wave of emplacement (indicated by "2") the Base of Operations emplaces bridges linking it additionally to Towns 2 and 4. After concluding operations these bridges can remain emplaced to be used by the local population.

Figure 2. Humanitarian employment of 3D concrete. *(Figure provided by author.)*

In addition to the above resource advantages, productivity is enhanced via the removal of forms—a point discussed in previous paragraphs. When utilizing 3D printing, the remaining resources—the fireteam of Marines, carpentry tools, and Class IV (construction) materials—could be allocated to another project, thereby increasing the productivity of the Marines, equipment, and materials.

Third, 3D printing has a cost advantage over traditional means. For this example, 3D-printed wall sections are being compared to MIL 1 HESCO barriers. MIL 1 barriers are approximately 4 feet tall, 3 feet wide, have a core filled with dirt or sand, and cost an estimated $240 per every 15 feet. To construct the same object out of 3D printed concrete, using a uniform wall thickness of 4 inches would use approximately 2 cubic yards of concrete, which is estimated to cost $200—a cost reduction of 16.6 percent. However, the true cost advantage of 3D concrete printing is the ability to maximize a design for cost while still retaining required properties of the end design. If the wall thickness could be reduced to 2 inches instead of 4, and still provide the same ballistic protection, the cost-maximized design would use approximately 1.33 cubic yards of concrete, which is estimated to cost $130: a cost reduction of 46.8 percent. By combining ballistic testing, structural load testing, geometric advantages, and material characteristics, designs could be maximized for cost purposes while still providing the required protection, strength, and size.

Marines, Sailors, and Soldiers work together to make concrete. *(Photo by LCpl Betzabeth Galvan.)*

Step	TRADITIONAL
1	Identify need: fighting position with firing ports in front and sides
2	Design fighting position 1 
3	Design forms
4	Build forms
5	Pour forms
6	Remove forms
7	Fighting position 1 - COMPLETE
8	Identify deficiencies: dead space within fields of fire
9	Redesign fighting position 1.a 
10	Design forms
11	Build forms
12	Pour forms
13	Remove forms
14	Fighting position 1.a - COMPLETE
15	Identify deficiencies: Curved edges provide better blast protection than angled edges
16	Redesign fighting position 1.b 
17	Design forms
18	Build forms
19	Pour forms
20	Remove forms
21	Fighting position 1.b - COMPLETE

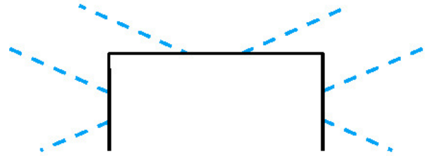
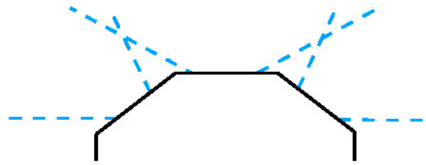
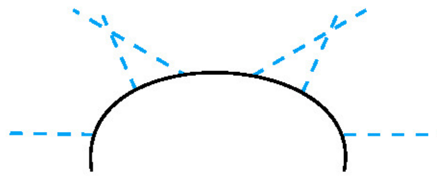
Step	CAD (3D PRINTING)
1	Identify need: fighting position with firing ports in front and sides
2	Design fighting position 1 
3	Render fighting position 1 in CAD
4	Print fighting position 1 - COMPLETE
5	Identify deficiencies: dead space within fields of fire
6	Redesign fighting position 1.a 
7	Render fighting position 1.a in CAD
8	Print fighting position 1.a - COMPLETE
9	Identify deficiencies: Curved edges provide better blast protection than angled edges
10	Redesign fighting position 1.b 
11	Render fighting position 1.b in CAD
12	Print fighting position 1.b - COMPLETE

Table 1.

Item	TRADITIONAL	Item	3D PRINTING
1	(13) 1371s	1	(8) 1371s
2	Hammer(s)	2	Concrete printer
3	Nail(s)	3	Fine aggregate
4	Saw(s)	4	Coarse aggregate
5	2″x 4″x 8′	5	Water
6	3/4 inch plywood	6	Dry Admix
7	2″x 6″x 8′	7	Wet Admix
8	Fine aggregate	8	Rebar
9	Coarse aggregate	9	Wire Mesh
10	Water	10	Rebar cutter
11	Dry Admix		
12	Wet Admix		
13	Rebar		
14	Wire Mesh		
15	Rebar cutter		
16	Concrete mixer		

Table 2.

Finally, 3D concrete printing technology provides a production capability advantage that has been previously unattainable. The important concept to understand is that 3D concrete printing is not a technology to build a better bridge, bunker, or obstacle. It is a technology to build whatever the commander needs to enable his desired effect within the battlespace. Instead of pigeonholing this technology to specific tasks or construction efforts, it is essential from the onset to understand that this technology is a production capability limited by the imagination of the user. Bridges, bunkers, billeting spaces, obstacles, road repair, runway construction, and force protection are all achievable efforts when paired with 3D concrete printing. Additionally, all these efforts would require the same inputs (Marines, materials, power, etc.) regardless of the differences in the project. With the proper development and focus, this technology is a multi-tool on the structural scale, a singular machine able to fix a vast range of problems.

7th Engineer Support Battalion Marines and Naval Mobile Construction Battalion 5 used the automated construction of an expeditionary structure printer to conduct 3D printing. *(Photo by LCpl Betzabeth Galvan.)*

In closing, 3D concrete printing is an emerging technology with valid application by future Marine Corps engineers. Its versatility, reduction of logistical requirements, ability to reduce personnel requirements, and potential to enable custom solutions to individual problems uniquely position this technology for strong consideration as equipment of the future Marine engineer. Its applicability in both combat and humanitarian operations makes this technology relevant regardless of mission set. By expanding a commander's capabilities while simultaneously reducing logistical needs, 3D concrete printing fits well into the greater EABO concept. Considering the wide range and scope of projects across all functions of Marine Corps engineering that a single printer could enable, coupled with the few raw materials and ingredients required to use it, 3D concrete printing is a technology where less truly is more.