



CONCRETE MIXES GUIDELINE

DRAFT

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Foreword:

The intention of the EWB-USA guideline series is to provide the basic requirements and information for making informed decisions when investigating and designing sustainable systems in developing countries. This guide does not replace the need for supervision of the project by an experienced concrete professional.

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1.0 INTRODUCTION

Many projects will not have access to contractors and ready-mix batch plants for a source of concrete, and the concrete will have to be mixed in the field. These guidelines cover a brief understanding of materials and field techniques for obtaining materials and mixing concrete in the field without powered equipment.

This guide is intended for EWB members who are involved in the design and implementation of a project. The following sections are written both as requirements, to make EWB projects more consistent and accountable, and as a brief and developing knowledge base to document methods that have worked in the past. Portions of this guide (such as sections 3 and 4) may be appropriate to revise and translate for local laborers, depending on their level of skill.

This is not meant to be a comprehensive guide, and there are further references available in an appendix.

2.0 CONCRETE MATERIALS

Concrete is a building material that has high compressive strength and low tensile strength and is composed of a mixture of cement, gravel and sand (aggregates), and water. *Reinforced Concrete* is the same material matrix combined with reinforcing steel (rebar) or wire mesh to provide tensile strength properties that allow for the construction of beams, columns, and floors. *Mortar* is a mixture of cement, sand and water that has more plasticity and workability than concrete and forms a good bond between masonry units of stone or brick. *Reinforced Masonry* incorporates wire mesh or rebar between regular masonry courses to build stronger walls for greater load bearing or for use in seismic areas.

Material quality greatly influences final concrete strength. The properties of each of the materials must be understood in order to evaluate and maximize the quality of the concrete produced.

2.1 Cement

Cement is a building material made by grinding calcinated limestone and clay to a fine powder. It is commonly available throughout the world, but its quality can vary tremendously within regions. Unit sizes are typically 94-lbs (1 ft³) or 50-Kg bags (33 liters).

When water is added to cement, it begins a chemical reaction called hydration, which is an irreversible curing process. This makes cement very sensitive to moisture and humidity, as water in any form will begin the reaction. Therefore, make sure that the cement purchased is powdery and has not begun to set, which is indicated by hard blocks or crust.

Cement should always be used as soon as possible after purchase, if not, store the cement off the floor in a dry room, well protected from rain. In the event that a crust develops on the surface of the material in the bag, this crust **must** be discarded as it will lower the strength of the mix if it is used. Cement bags should be stacked such that the older bags will be used first.

2.2 Aggregate – Sand and Gravel

In the US, sand and gravel used in concrete is defined by ASTM C33, which defines the proportions of particle sizes that are used. Concrete is stronger and more structurally efficient when all particles in the mix are well graded in size. If all of the particles are of the same size, there will be many spaces that must be filled by the cement and water.

The coarse aggregate (gravel) should be rough and clean with broken faces; rounded particles will not adhere well in the mixture and should be avoided, if possible. Dirt and organics in the mixture will also decrease mix strength, and any aggregate containing soils must be washed until clean. Gravel obtained from quarries where it has been crushed is the best source. Riverside gravel should be broken with a hammer to form rougher surfaces.

Maximum gravel size is always 3 inches, but is usually smaller and dependent on the formwork and dimensions of the rebar. Aggregates larger than 2 inches will usually reduce concrete strength. Maximum aggregate size must be less than:

- 0.2 times narrowest dimension between form walls
- 0.33 times depth of slab
- 0.75 times the clear distance between rebar, or from rebar to the exposed surface

Sand sizes should also be well graded. The best design has 50% medium size particles with decreasing amounts of very large and very small particles. Thus, if there is a supply of very fine sand (such as found in many beaches), it should be thoroughly mixed with coarser sand from another location. Typical pictures of washing sand are shown below.



Washing sand at a river



Washing sand at an industrial site

2.3 Water

Water used should be of potable quality if possible, but in no case should dirty or saline water be used. Water sources from rivers or groundwater are usually suitable for making cement mixtures. Do not use water from standing ponds or swamps; this water may be high in organic materials.

2.4 Rebar

Ribbed reinforcing steel used in concrete applications is called rebar. Rebar for smaller applications will be from 3/8" to 8/8" in diameter, and the numerator, measured between the ribs, will define the size in standard units (i.e. 5/8" rebar is called 'Number 5 Bar'). Metric equivalents will more commonly be found outside North America. Smaller diameter bars generally perform better structurally, although they may be of lower quality than larger bars made in bigger factories. Thus, the design should use more smaller bars instead of fewer larger bars, if possible. Additionally, smaller bars will be easier to transport, cut, and bend than larger diameter bars. Bars up to 5/8" are easily manipulated with hand tools. Only newer bars with minimal surface corrosion should be used, and in no case should oil or other lubricants contaminate bar surfaces before pouring. Bars are generally sold in 6m (20') lengths for sizes less than #7 (though in some cases 9m (30') lengths), and 3m (10') for #7 and larger sizes.

Cutting of smaller bars is best done with hack saws, or bolt cutters for very small sizes. Cut approximately half way through the bar and then bend to shear the remaining area. Larger bars (greater diameter than #6) are easier to cut with levered tools called 'breaks.' However, a break specifying '#8 capacity' will not cut that size with ease, or repeatedly before chipping the carbide cutting surface. Breaks are helpful with smaller sizes if a large quantity of bars must be cut, though hacksaw blades may be cheaper. Cutting torches can be used on larger bars, but this can affect metallurgical properties of the bar and should be avoided if other options are available. Grinders also work well if power is available.

Bending smaller bars can be accomplished with pipes of slightly larger inside diameter than the rebar. Larger bars can be bent with a bending table along with pipes. A table is also useful if numerous stirrups must be fashioned for a project, as it allows more precise dimensioning. Bending of bars larger than #5 requires professional equipment. A typical picture of bending bar in the field is shown below.



Bending rebar in Ethiopia

3.0 MIX DESIGN

A concrete mix is selected based on the intended application and is mixed by a ratio of cement:sand:gravel:water. The ratios may be expressed by volume or weight, but mixing by volume is more practical in the field where scales are scarce and plastics buckets are in abundance. Concrete mixes by volume and their common applications are shown in Table 3.1.

Table 3.1: Concrete Mixes by Volume and Use

| Mix Ratio (Volume) (Cement:Sand:Gravel:Water) | Use | Aggregate Volume, liters (cf) per 50-kg bag of cement | Approximate Yield, m ³ (cf) |
|--|---|---|---|
| 1 : 3 : 6 : 1.6 | Large Aggregate, Mass Foundations, Kick block anchors | Sand 130 (4.6) Gravel 180 (6.4) Water 70 (2.4) | 0.24 (10) |
| 1 : 2.5 : 5 : 1.6 | Foundations on poor soil | Sand 110 (3.9) Gravel 160 (5.7) Water 70 (2.4) | 0.21 (9.5) |
| 1 : 2 : 4 : 1.6 | Medium Aggregate Floors, nonstructural Walls | Sand 80 (2.8) Gravel 130 (4.6) Water 70 (2.4) | 0.17 (8.0) |
| 1 : 2.5 : 3.5 : 1.6 | Small Aggregate Beams, Structural Walls | Sand 110 (3.9) Gravel 115 (4.0) Water 70 (2.4) | (8.0) |

(Adapted from the Cement and Concrete Assoc. Construction Guide).

The amount of water in a mix is critical to the strength of concrete. For hand mixing, a water/cement (w/c) ratio of approximately 0.5 by weight gives a strong concrete (unit weight of dry cement is approximately 94 lbs/ft³). The higher the w/c ratio, the better the workability (which the workers prefer), but the lower the strength. If the quality of the cement is questionable, the best way to ensure good concrete without affecting mix design and volumes is to increase the amount of cement by 10%. However, as cement contributes most of the cost to concrete, increasing this percentage also increases the unit cost of the mix. Internet resources such as <http://ciks.cbt.nist.gov/cost/> provide a guide to optimize mix design, but with caution as the quality of the local resources are of primary importance.

Generally, a proper w/c ratio concrete will appear to have too little water. However, many factors affect the amount of water that can bond with the cement, such as initial moisture in aggregate, evaporation, absorption by the aggregate, and aggregate surface area. These factors may justify higher water content, at the engineer's discretion. Note that because the cement is generally only about 15-20% of the mix volume, a small addition of water will increase the ratio significantly (for 100lbs of concrete, adding 2lbs of water will increase the w/c ratio from 0.5 to 0.6). Therefore water must only be added in small amounts. Members of the team should practice mixing in a lab or jobsite before going to a project site.

Most importantly, team members must be prepared for unfamiliar and possibly inferior mixing and construction techniques in other cultures, and apply these guidelines carefully when working with experienced local carpenters.

4.0 MIXING, FORMING, PLACING, AND CURING

4.1 *Measuring and Staging*

The cement and aggregate should first be mixed dry in a small pile until a uniform color and density is achieved. The least labor intensive method of mixing is to add enough aggregate for 1 bag of cement, mix and then continue with another bags worth of aggregate and so on (as opposed to adding all aggregate, and several bags of cement). Once all the dry materials are mixed, water should be added slowly by sprinkling instead of pouring, and the mixture should be further mixed until it is of a uniform color and consistency; a perforated watering can works well for this procedure.

Due to the many factors that affect the water content (humidity, absorption etc.), it is best to add approximately 90% of the water to start. Then add water until the proper consistency (slump) is reached. Remember that more water can always be added, but not removed. After several batches, the team members and local workers should have a feel for the correct proportion of water.

A level, hard mixing pad is necessary for preparation of the mixes; this can be prepared ahead of time using a 1:6 cement:sand mix (add water until until workable) on level ground. A pad approximately 2 meters in diameter works best, and each mixing team should have their own pad. A good mixing team size is four workers trading mixing duties, four laborers supplying materials and water, and one supervisor. Material preparation may vary greatly according to local custom, but in general the use of concrete is widespread enough that experienced local labor can be found for these tasks. Typical mixing in the field is shown in the pictures below.



Mixing the dry materials

Sprinkling water on mix

4.2 *Formwork*

If formwork is used to form structural items such as walls, columns, beams, it should be left in-place for at least 2 days. Formwork reduces the rate of water evaporating from the

concrete mix and provides a more thorough curing process. Forms should be designed structurally to contain a 150 pcf liquid. Nails have a low pullout strength and should be used as shear resisting elements, or toe-nailed at opposing angles when they are to be used in tension. Typical forms in the field are shown in the pictures below.



Column form

Slip form for bridge abutment

4.3 Placing

Concrete should be carefully placed, not dropped, to prevent the segregation of the cement and sand from the larger gravel aggregate. Typically, concrete should not free-fall more than a few feet, and workers should be prevented from throwing concrete with shovels or buckets. Immediately after placing, it should be rodded with spare rebar. This reduces strength-reducing air voids. This is especially important around reinforcement.

Before mixing large amounts of concrete, it is important to coordinate efforts on how the concrete will be placed. If a large deep footing is to be placed, such as for bridge spread footings, it should be placed in 6" lifts, to eliminate vertical cold joints. In addition, in large slabs, concrete should be placed from one end to the other, not started in the middle, or placed converging from different directions. And once concrete has begun to set, it should not be moved, as this will weaken the final structure. The location of cold joints should be incorporated into the structural design in larger structures.

The amount of concrete that can be placed in a day obviously depends on the size of the team pouring. A team of 10 laborers can usually mix and place 150 cubic feet in 3-4 hours. [that sure seems like a lot to me. I have done 3m³ in a day before with about eight people, but your dead after that.]

4.4 Curing

When working the concrete to the final finish, water will typically appear on the surface called "bleed water". This water should not be removed as it will help keep the moisture needed for hydration from evaporating too quickly. In addition, concrete should be kept moist for the first month after pouring. This is especially important for mortars joints and

cold joints. Depending on the climate (humid areas require almost no help), this can be accomplished by wetting the surface and covering with a waterproof cover (most important for the first night). Water should then be poured on the curing concrete twice a day for the next three weeks. Poorly cured concrete will show shrinkage cracks, will not provide good strength, and will deteriorate more quickly.

5.0 MATERIAL STRENGTH ASSUMPTIONS

Structural calculations require the material strengths for the concrete and rebar. As one weak batch of concrete or piece of rebar can govern the integrity of the structure, conservative assumptions must be made in design, and quality control must be maintained during mixing. EWB members shall be responsible for providing consistent supervision by qualified personnel during mixing.

In addition, the following tests shall be conducted:

5.1 Field Testing

Slump test: A slump cone (purchased in the US) should be filled with the concrete in three equal layers, each rodded 25 times (per ASTM standards). When the cone is lifted, the concrete will “slump” and the distance of the slump should be measured in inches. A slump between 4 and 5 is practical for most structural work and 5 to 7 where workability is important, such as non-structural slabs. It is best to do this for the first several mixes, or to help determine water content if it is problematic.

5.2 Lab Testing

Tests should be done locally in the project country if possible. However, if the equipment or expertise is not available, the materials should be transported back to the United States and tested.

Compression Test – Plastic cylinders (4-inch diameter, 8-inch height, purchased in the US) should be filled in two layers, each rodded 25 times. Particularly large aggregates should not be put in the cylinder as it will yield artificially low results. These should be moved minimally for the first 24-48 hours, after which they may be transported to a laboratory for compression testing. Each cylinder is approximately 0.058 ft³ and will weigh approximately 8 lbs. Official paperwork to certify the contents of the plastic cylinders (not an illegal substance) should be carried if possible to facilitate customs clearance (assume that at least one will be destroyed). The results of these tests will help in future portions of the project and future EWB projects.

Tension test – bring several pieces of rebar, 12-18 inches long, back to be tension tested. Some 60 ksi bar has been used around the world, but it is mixed with 40 ksi bar (since they are visually identical). This is especially important for projects requiring large amounts of rebar (such as bridges), as the bar is the same costs.

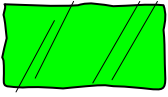
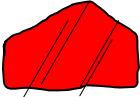
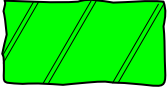
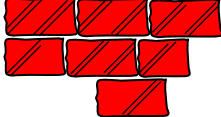
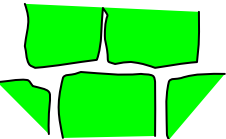
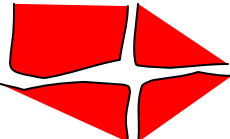
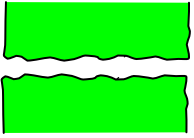
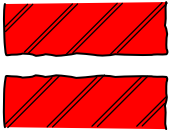
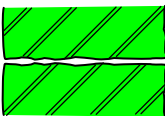
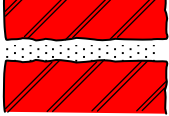
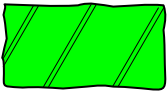
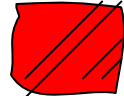


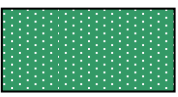

6.0 MORTAR MIXES

Mortar is composed of a sand, cement and water and is usually used in masonry to hold together stones, bricks or cement masonry units (CMU). The most useful mixture is usually 1:4 cement : sand, with water added until workable. Mason skill is generally dependent on the culture.

While the cement is freshly mixed, it should be placed and fully compacted, using a blunt instrument or the hands. Mortar will usually bond within 30 minutes, after which new cracks formed by disturbing the mix will not re-bond. If the mortar is placed after this initial setting time is reached, the mortar will not adhere to stone or cohere to itself, and the following day it will have the consistency of large granular sand. It should then be removed as thoroughly as possible and new mortar must be applied. This will also occur if stones are moved and the bonds broken after the setting period.

The engineers shall be wary of and investigate the fabrication of local CMU's. In many places, these are abundant, but very weak. They are generally made with poorly graded granular sand and very little cement content. These should not be used for structural applications. If blocks are appropriate for the project, special blocks can sometimes be ordered with a higher cement content, for a higher price, but the construction of these should be supervised. A general guide to masonry is shown on Table 6.1 below.

Table 6.1: General Guide to Stone Masonry

| ...HIGHER... | The Strength of Stone Masonry is... | | ...LOWER... | |
|---|---|----------------------------------|---|---|
| ...with rectangular stones. |  | Form or Shape |  | ...with irregular shaped stones. |
| ...the less stones are used. |  | Number |  | ...the more stones are used. |
| ... when the vertical joints are staggered. |  | Position of joints |  | ...when the vertical joints are in line with the joint above. |
| ...the rougher the joints are. |  | Roughness of joints |  | ...the smoother the joints are. |
| ...the smaller the beds are. |  | Bed |  | ...the bigger the beds are. |
| ...the wider the stones are. |  | Height & Width |  | ...the slimmer the stones are. |
| ...the deeper the bond inside is. |  | Bond Across (in top view) |  | ...the worse the bond inside is. |
| ...the lower the amount of water in the mortar. |  | Strength of Mortar |  | ...the higher the amount of water in the mortar. |

From Helvetas Nepal Bridge Building at the Local Level (Trail Bridge Sub-Sector Project) Suspended Bridge Building Manual.