Rapid Response Techniques for Disasters Near Roadway Work Zones

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16. Abstract Roadway contractors and construction engineers are often tasked with three overlapping objectives: minimizing traffic delays related to construction, reducing the risk of traffic crashes in work zones, and protecting the health and safety of workers and the public. Major difficulties can arise when a closure due to road or bridge construction coincides with an adverse event such as a severe storm, earthquake, or forest fire. It is sometimes possible to handle the situation by reopening traffic lanes in the main construction area, but in other cases it may be necessary to build a route quickly. This document discusses options and techniques for building expedient roads and trails that can allow first responders to reach a stricken area, facilitate evacuation of the area, allow traffic to bypass the area, or restore access while damage to roads and bridges is being repaired.			
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Rapid Response Techniques for Disasters Near Roadway Work Zones

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June 2022

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Chapter 1. Expedient Roads and Trails: An Overview

Introduction

Roadway contractors and construction engineers often have to deal with traffic issues, including minimizing construction-related traffic delays, reducing the risk of work zone crashes, and protecting the health and safety of workers and the public. When there are abrupt changes in traffic and weather conditions, engineers and contractors need tools and strategies for responding quickly, efficiently, and effectively.

Major difficulties can arise when a road or bridge construction closure coincides with an adverse event such as a severe storm, forest fire, or earthquake. It is sometimes possible to handle the situation by reopening traffic lanes in the main construction area. In other cases, it may be necessary to build a route quickly, such as that shown in Figure 1.

Figure 1. Temporary road bypassing a bridge washout.

These **expedient roads and trails** typically serve one or more of the following functions:

- Allow first responders to reach a stricken area
- Allow residents to evacuate the area
- Allow traffic to bypass the area
- Restore access while construction is completed or major damage is repaired

This document uses the term *expedient* to describe facilities that can be built very quickly, mainly using locally available materials, equipment, and personnel. To a degree, they can be distinguished from *temporary* facilities, which might have a longer service life, could involve more advance planning, and might require bringing specialized materials, equipment, or personnel to the site. In practice, the two categories overlap considerably, and what gets built is more important than what it is called.

Expedient roads and trails typically have the following characteristics:

- Used for a short time (generally less than one year)

- Carry low-speed traffic (usually 30 mph or less)
- Do not need to carry large volumes of heavy traffic but might need to accommodate emergency vehicles such as fire trucks
- Limited to one or two lanes; if the road has only one lane, pull-outs can be provided at strategic locations to make it easier for vehicles traveling in opposite directions to get around each other

While many expedient roads serve motor vehicle traffic, the most immediate need is often to evacuate pedestrians or to facilitate access for light emergency vehicles such as all-terrain vehicles (ATVs). As a result, the expedient road or trail could carry different types of traffic than the normal route. For example, the temporary river crossing shown in Figure 2 is designed to carry pedestrians and light vehicles.

Figure 2. Floating bridge for a temporary river crossing and its approach road.

Several factors affect the design and construction of an expedient road or trail:

- Status of the main road or bridge construction project at the time of the adverse event
- Status and usability of other alternative routes, if any exist
- Severity of actual or expected damage from the adverse event
- Size and population of the impacted area
- Timing of the adverse event
- Type, size, and weight of the traffic to accommodate
- Expected service life for the expedient route
- Resources (personnel, materials, and equipment) available to build the expedient route

For simplicity, the remainder of this document refers to all expedient routes as "roads" or "roadways." In practice, some could be more like "trails" in the sense that they primarily serve pedestrians, ATVs, or other light vehicles.

Document Content. The content of this document is intended to support traffic management decisions resulting from combinations of construction and adverse events. The first chapter explains why adverse events such as forest fires, floods, and hurricanes are becoming more common in the United States and provides a high-level overview of some techniques for building emergency roads quickly. The remaining chapters describe the process for establishing an expedient roadway and the selection of appropriate components such as temporary surfacing materials, temporary culverts, temporary low-water crossings (LWCs), temporary bridges, and temporary roundabouts.

Planned versus Unplanned Situations. When a road construction project is being developed for an area that is vulnerable to adverse events, potential expedient roadway needs can be preplanned as part of the project development process to support a well-organized disaster response and recovery process. Nevertheless, this document recognizes that unexpected emergencies can and do occur. Examples of such events and their effects are shown in Figure 3, and the following section explains the growing risk of adverse events in the United States. Unexpected emergencies create an urgent need for expedient roads to manage traffic already impacted by the combination of roadwork and an adverse event.

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Figure 3. An expedient road may be needed when damage to an existing route cannot be restored quickly.

In these cases, there could be a shortage of road-building materials, personnel, or equipment, and it may be necessary to make do with the resources that are at hand. For this reason, the main focus of this document is *unpaved temporary roads that can be built using widely available materials* such as gravel, wood chips, or dirt.

Various types of prefabricated temporary road panels are commercially available. These systems are worth considering as part of a planned areawide resilience strategy or a contingency plan for a forthcoming construction project. With sufficient advance planning, the necessary components (and the tools and equipment for installing them) can usually be stored near the project site. A few examples of prefabricated systems are briefly discussed later in this chapter, but comparing the strengths and weaknesses of the various commercial products is beyond the scope of this document.

Non-highway Solutions. Responding to disasters requires innovation. Occasionally, non-highway options can resolve an area's temporary transportation needs. For example, a river runs through the middle of Workington, England, a community of 25,000 people. In 2009, flooding damaged all of the street, highway, and pedestrian bridges across the river (Guiver 2011). In response, temporary train service was implemented to reconnect the two halves of the municipality using an existing, undamaged rail line, as shown in Figure 4 and Figure 5. In addition, some retailers and government offices temporarily opened second locations to serve people on both sides of the river. This was soon augmented by a temporary pedestrian bridge that facilitated access to the commercial district for several months while the permanent bridges were rebuilt.

Figure 4. A railroad bridge was the only unaffected river crossing following the 2009 flooding in Workington, England.

Figure 5. Temporary passenger rail service reconnected Workington, England, while pedestrian and roadway bridges were rebuilt.

Why Disaster Risks Are Increasing

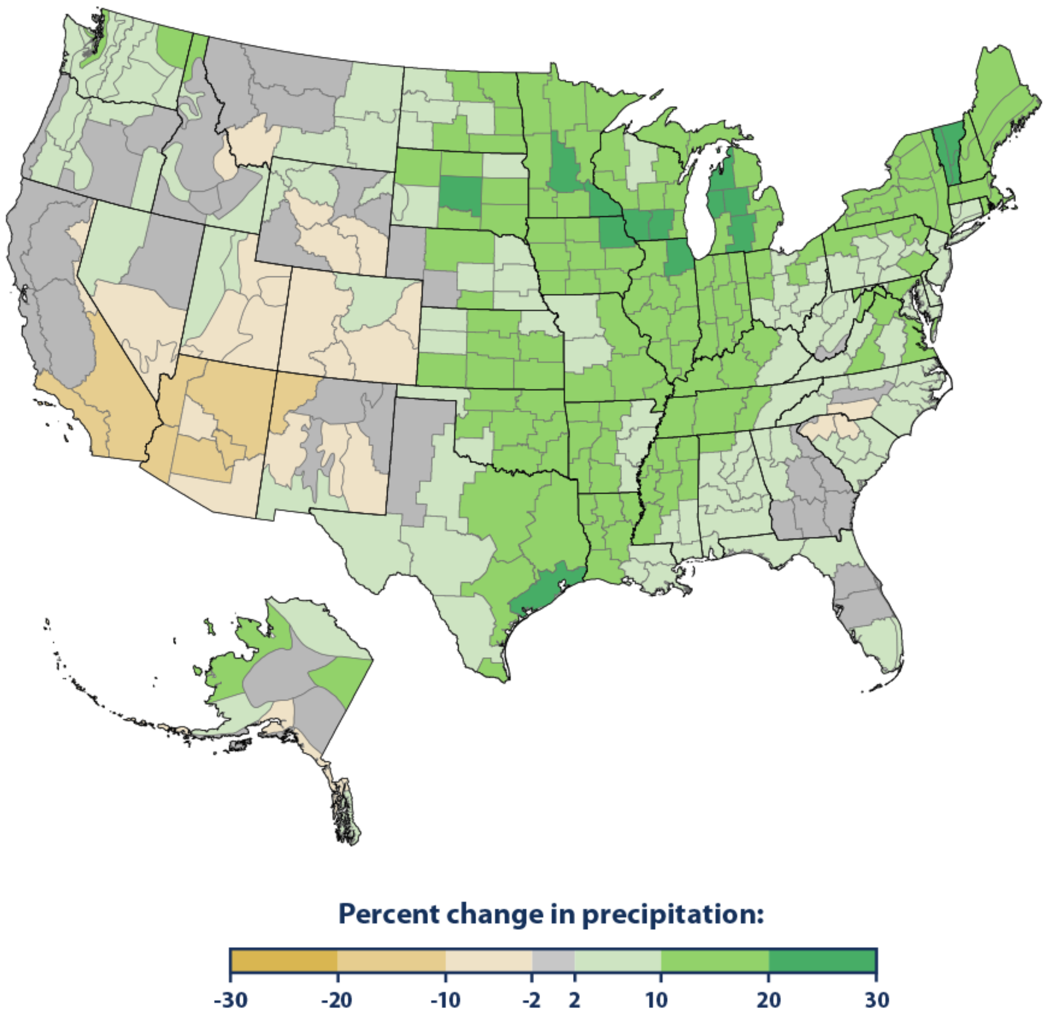
In recent years, many parts of the United States have experienced increases in the frequency and severity of adverse weather-related events. These changes increase the probability of disasters occurring at the same time as long-term closures for road or bridge construction and make the topic of expedient roads especially timely.

Many types of disasters can affect and interact with work zones. Some are unrelated to weather, such as earthquakes, train derailments, and industrial incidents. Others, such as forest fires, floods, hurricanes, and landslides, arise from the short-term and long-term effects of temperature and precipitation (or lack of precipitation). These relatively rare events often have long-lasting consequences.

In the past, a construction engineer or contractor might have regarded such an incident as a once-in-a-lifetime event. Today, adverse weather-related events are becoming more common and more intense, and this is expected to continue in the future (USGCRP 2017). As Pam Dingman, County Engineer in Lancaster County, Nebraska, puts it, "When we had our third 500-year flood, we knew something was up."

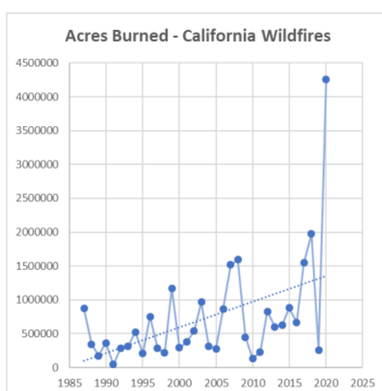
As shown in Figure 6, the National Weather Service has been collecting comprehensive daily weather records for the United States for well over a century. These data reveal important changes over time, such as the following:

- The Southwest, especially southern California and Arizona, is receiving up to 30% less precipitation than it used to. Warmer temperatures and this drier weather are major factors in the increasing frequency and size of forest fires in California and other western states, as shown in Figure 7.
- The Upper Midwest is getting up to 30% more precipitation than it used to. This wetter weather has increased the risk of flooding along the Mississippi River and its tributaries, as shown on the map in Figure 8, with downstream impacts in the South-Central states.
- The East Coast and Gulf Coast are increasingly susceptible to hurricanes and other tropical storms, as shown on the map in Figure 9. Not only are there more storms; their intensity has increased. The resulting increases in precipitation in Texas and Louisiana are particularly notable.



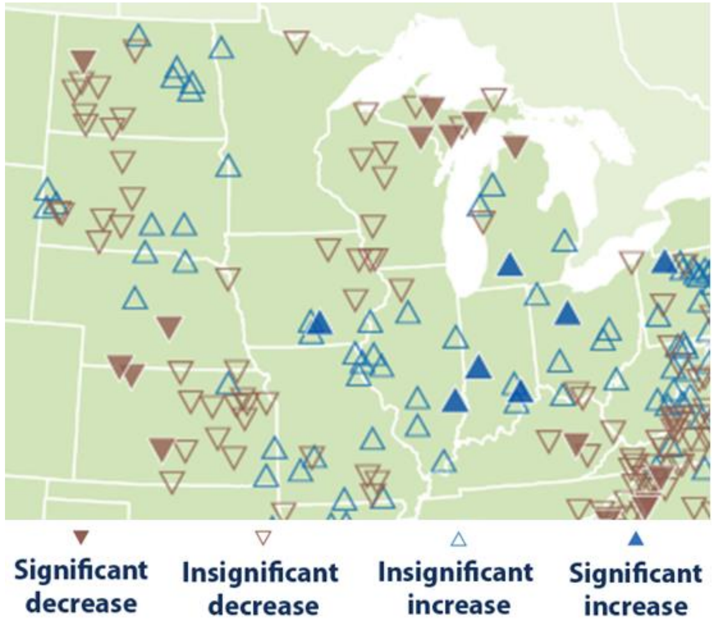
NOAA

Figure 6. Change in precipitation in the United States 1901–2020 (with Alaska data starting in 1925).



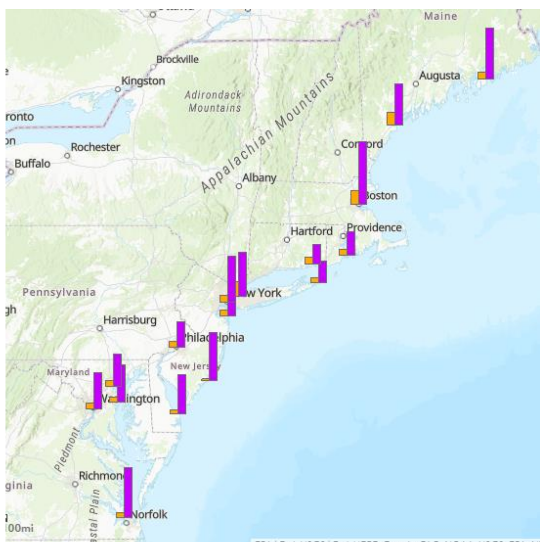
CalFire (State of California)

Figure 7. Change in annual total acres burned in California wildfires, 1987–2020.



Adapted from EPA

Figure 8. Changes in the magnitude of river flooding in the central US, 1965–2015.



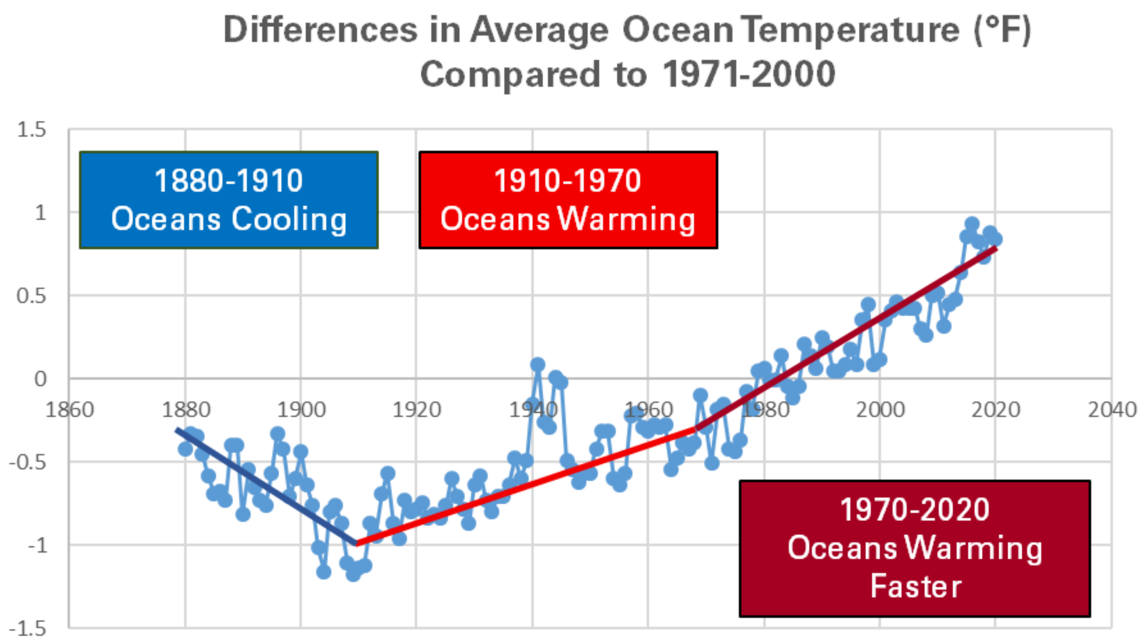
NOAA/EPA

Orange bars (at left of set) indicate 1950s; purple bars (at right of set) indicate 2010s.

Figure 9. Number of flood days at coastal locations.

In many cases, the effects of these changes are amplified by current land development and forest management practices. For example, when vegetation is removed to construct buildings, streets, and parking lots, the acreage of impervious (nonabsorbent) surfaces usually increases. This results in more runoff from storm events along with faster flow toward downstream waterways, especially if stormwater storage facilities such as retention ponds are too small.

Accurate weather information is crucial for the safe operation of military and civilian ships. Naval logbooks provide meticulous weather records spanning the world's oceans. As shown in Figure 10, these records indicate a steady increase in the sea surface temperature since about 1910, and the rate of increase has accelerated since about 1970.

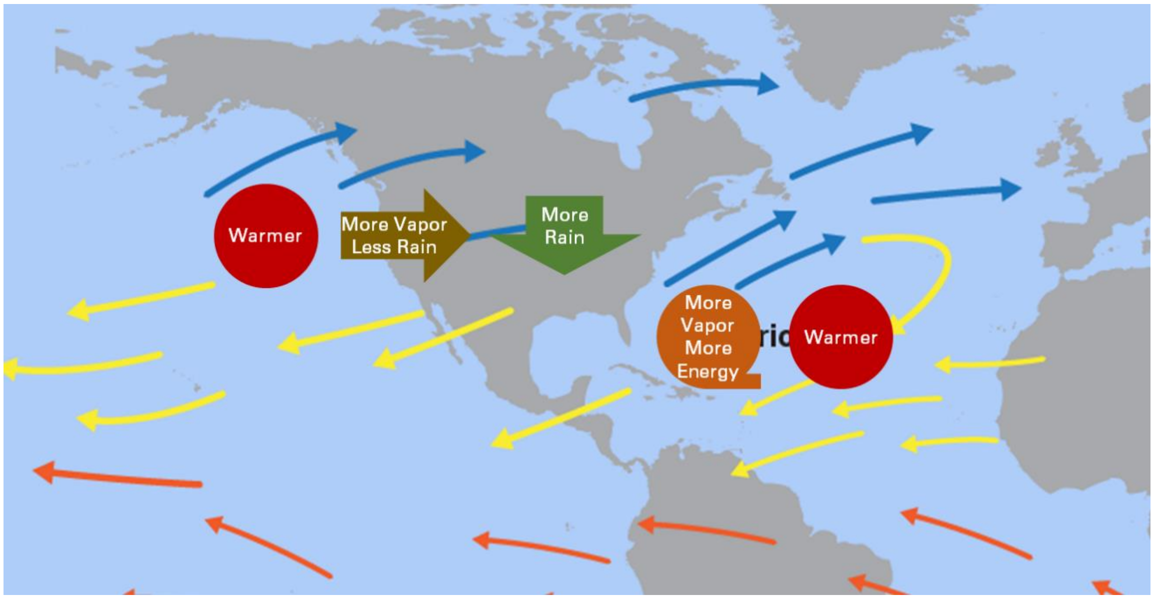


NOAA/EPA

Figure 10. Chances in ocean surface temperature, 1880–2020.

It might seem strange that one part of the country is getting substantially drier while another is becoming much wetter. As shown in Figure 11, this is mainly due to wind patterns. In most of the United States, the prevailing wind is from the west. Warming of the Pacific Ocean increases the amount of water vapor in the clouds approaching the west coast of the United States. Since the land is also warmer, clouds travel farther inland before condensing into rain or snow (USGCRP 2017). As a result, less rain is falling in the West, and more is falling in the Midwest and South-Central regions.

In the Atlantic Ocean, the prevailing west winds in the mid-latitudes (blue arrows in Figure 11) shear against east winds closer to the equator (yellow arrows in Figure 11). This can create rotation, spinning up tropical storms. As the waters of the Caribbean have become warmer, the amount of water that evaporates into vapor has increased, and storms have become more intense. As a result, storms are more likely to reach the United States mainland. This increases the probability that hurricane evacuations could coincide with construction-related roadway closures.



Base map: NASA/JPL-Caltech

Figure 11. Warmer water in the Pacific and Caribbean interacts with the winds to change the location and amount of precipitation in the United States.

Although construction engineers and contractors have no direct control over these weather changes, understanding the long-term nature of the situation can help guide response decisions. Extreme weather events are likely to become more numerous in the future (USGCRP 2017). From this perspective, the use of expedient roads and trails serves as an important first step in the process of "building back better" to provide lasting resilience against future adverse events.

Characteristics and Components of Expedient Roads

As shown in Figure 12 through Figure 21, the main components of an expedient road system include the road base, road surfacing, drainage structures, and other related items. Figure 12 and Figure 13 show the preparation of a road base and a road surface, respectively, for two different expedient routes.

Figure 12. If time and resources allow, vegetation and topsoil can be removed to improve the durability of a temporary road.

Andrew Camarata / https://www.youtube.com/watch?v=ey_NEoM2SpM

Figure 13. If available, geotextile can help stabilize temporary roads by spreading wheel loads across the underlying soil more evenly.

If drainpipe is not available to build a temporary culvert like the one shown in Figure 14, **box culverts** can be built using logs or timbers to bridge across abutments made by stacking bags filled with sand or gravel, as shown in Figure 15; this technique is discussed in more detail in Chapter 3 on bagged-aggregate construction. Bags of aggregate (sand or gravel) can also be stacked to build end walls for pipe culverts, wing walls, and **retaining walls**. Another expedient way to get stormwater across a roadway is to build a **trench drain** (also called a French drain) by digging a trench and backfilling it with open-graded gravel, as shown in Figure 16.

© Massachusetts Department of Environmental Protection

Figure 14. Temporary culvert backfilled with gravel.

Japan International Cooperation Agency / https://www.youtube.com/watch?app=desktop&v=zcG7cdKXKxU

Figure 15. Hand construction of a box culvert using timbers and compacted bags of gravel.

Scooter133 / Wikimedia Commons / Public Domain

Figure 16. Trench drains (trenches backfilled with gravel) can be installed to manage stormwater.

Low-water crossings, such as those shown in Figure 17 and Figure 18, are an expedient way to get the roadway across small waterways with limited or intermittent water flow and are discussed in more detail in Chapter 4. Larger waterway crossings could require **temporary bridges,** such as those shown in Figure 19 and Figure 20, which are discussed in Chapter 5.

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Figure 17. Gravel pads are sometimes adequate for crossing small waterways.

© John Poyser (Geograph) / Back lane and ford / CC BY-SA 2.0

Figure 18. Low-water crossings are an expedient solution for crossing small waterways.

Figure 19. Plank surfacing is sometimes used for temporary bridges.

Figure 20. Pontoon bridges have long been used for temporary crossings of large waterways.

Gabions (rock-filled wire baskets) can be used to shore up the toe of a slope, as shown in Figure 21, or to build retaining walls. Expedient gabions can be fabricated from fencing materials.

Figure 21. Gabions (rock-filled wire baskets) can be used to stabilize the toe of a steep side slope.

Other typical temporary road components include signs, railings, fences, and gates.

Planning and Designing Expedient Roads

Building a road quickly does not mean the work should be done haphazardly or without planning. There is still a need to determine what traffic will use the road, decide the road's location, ensure that its dimensions and load-bearing capacity can minimally support the traffic that needs to use it, and minimize potential problems such as erosion. In most cases, issues such as drainage need to be addressed to prevent the expedient road from becoming waterlogged or washing out. It is also important to ensure that there are no irreversible impacts on environmental resources such as wetlands or nesting grounds and to avoid damaging cultural resources such as historic buildings or archaeological sites.

Defining Functional Requirements. One of the most important early decisions is determining the expected uses and users of the expedient road. Typically, the road will serve one or more of the following functions:

- Allow first responders to access an area that has been cut off by the combination of road construction and an adverse event
- Allow residents (and possibly businesses) to evacuate a stricken area
- Allow general traffic to bypass a stricken area

The type of traffic to be accommodated by the expedient roadway could vary over time.

Adverse events typically unfold in four main phases:

- **Early Warning and Pre-event Evacuation.** While some adverse events (such as earthquakes) can occur without warning, others (such as hurricanes) might be predicted hours or days in advance. In these cases, the expedient road could play a role in efforts to prevent casualties and property damage, for example, through the evacuation of residents. Pre-event warnings can also provide opportunities to begin planning an expedient road or stockpiling appropriate materials and equipment.
- **Response.** This phase typically involves on-site activities by first responders such as firefighters, emergency medical services, and law enforcement. Providing assistance to injured people is usually the top priority. It is often necessary to manage both inbound traffic (such as fire suppression vehicles going into the site) and outbound traffic (such as ambulances transporting victims out of the site). Police checkpoints might be established to control access to the stricken area.
- **Recovery.** This phase typically consists of efforts to assess damage and recover the remains of any people killed by the adverse event. This is often followed by efforts to stabilize or salvage damaged property. Depending on the nature of the event, physical security might continue to be important.
- **Reconstruction.** This phase typically involves debris removal and repairs to buildings and other facilities in the affected area. Depending on the nature of the incident, there could be a desire to accommodate heavier loads for construction traffic during this phase.

Often, an expedient road is put in place to support the response phase of the disaster. Later, it might be upgraded to a temporary road to support heavier and wider loads during recovery and reconstruction. In most cases, it is removed (and the site restored to something close to its original condition) once a permanent replacement is completed. Thus, the expected duration of the event and its aftermath will help define how durable the road needs to be. Often the road will fall into one of the following categories:

E1: An expedient road that needs to be built quickly and is expected to be used for less than a month (perhaps only for a few hours).

E2: An expedient road that will be used for emergency response and/or recovery, with a service life of more than a month but less than a year.

E3: A road that needs to be built quickly like an E1 road and then upgraded at a later date to support subsequent recovery or reconstruction. The expedient road thus serves as a "pioneer road" that will be upgraded if necessary at a later time.

Consideration of these categories will help establish the design vehicle for the expedient road. For evacuations, the design vehicle might be an automobile, pickup truck, or sport utility vehicle (SUV). During response and recovery, the design vehicle might be an ATV, police car, ambulance, or firetruck. If firefighting vehicles are anticipated, local fire officials should be contacted (if possible) to determine whether all-wheel drive vehicles will be used, because this information could lead to a road design that can be implemented more quickly and with fewer human and technical resources.

Design Process. In an ordinary road-building project, designers spend several months to prepare a site survey; determine the type and amount of traffic to be served; evaluate the topography, drainage, soil, and underground utilities; and determine how to minimize any adverse social and environmental impacts. Detailed drawings are then prepared to balance functionality, site constraints, and cost. In the design of an expedient roadway, which will likely be an informal process, these steps are compressed into a much shorter time frame (perhaps as little as an hour).

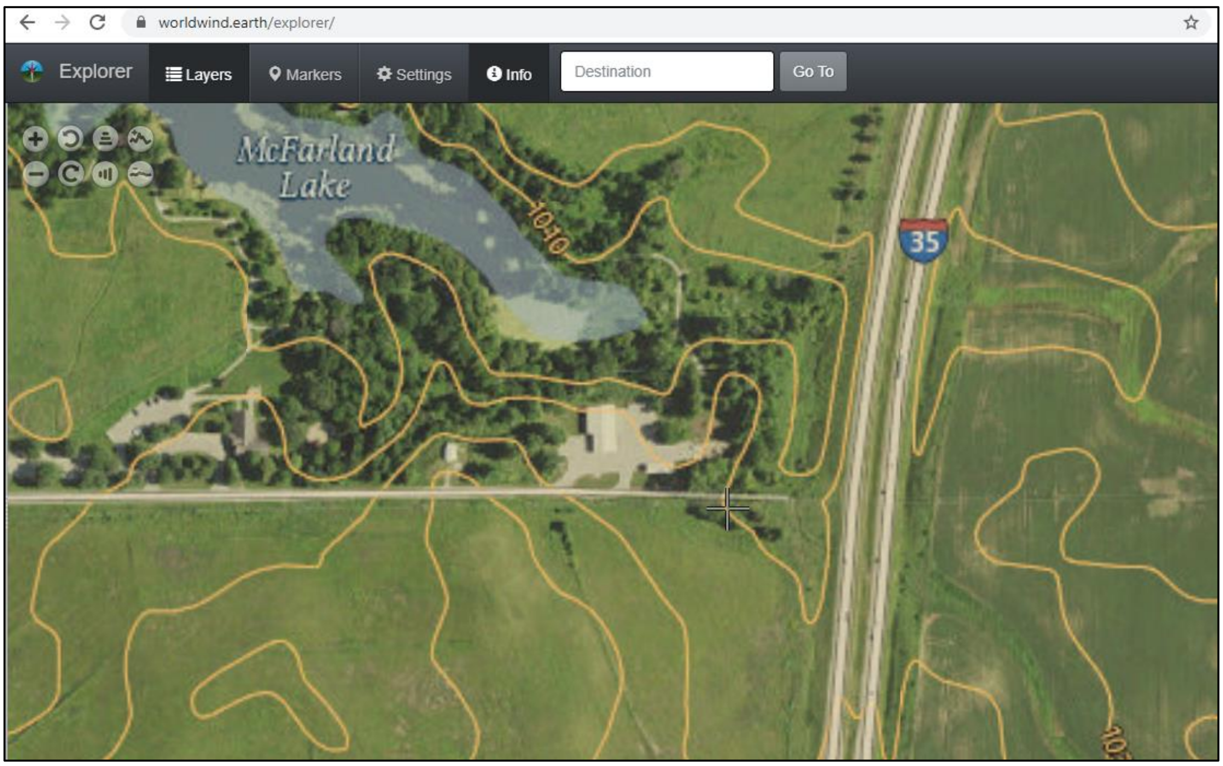
With the exception of preplanned situations, it is seldom possible to prepare a full set of design drawings for an expedient road. Instead, the "blueprints" might consist of a few hand-drawn sketches or simply some stakes in the ground. The instructions do, however, need to be sufficient for everyone working on the project to have a clear idea of what to do and how to coordinate their actions. For example, if one crew is working on culverts while another builds the rest of the road, it will be important for everyone to know the vertical elevation of each match point. The plans or instructions should also be sufficient to avoid unnecessary effort and wasted materials, such as for a road built wider than it needs to be.

For the purpose of this document, it is assumed that the expedient roadway has minimal environmental impact or is being built under emergency powers that override the standard environmental permitting processes. Nevertheless, environmental impacts should be minimized to the extent practicable. This includes making it easy to restore the site to its prior condition after the emergency has been resolved.

Site and Alignment Selection. Satellite images and topographical maps are valuable tools for determining the location of the expedient road. One useful tool for this process is Worldwind Explorer, a web application based on the National Aeronautics and Space Administration (NASA) Worldwind project, which provides both satellite imagery and topographical contours; an example map is shown in Figure 22. Other sources of satellite images include Bing Maps, Google Earth, and the United States Geological Survey (USGS) National Agriculture Imagery Program (NAIP). Bing Maps and Google Earth are online tools, while USGS NAIP provides downloadable imagery that can be viewed with GIS tools such as ArcGIS or QGIS. USGS TopoView provides online access to detailed topographical maps for the entire United States. These readily accessible mapping resources can help designers determine how to connect the expedient road with existing facilities in a way that makes the best possible use of available resources.

Although satellite images and topographical maps provide valuable information, some on-site reconnaissance will probably be needed. A typical workflow is to use maps and images to narrow down the possible alignments for the expedient road and then make the final selection on site. Site photos should also be collected during the field visit to assist with design. These photos should be saved to help guide restoration of the site to its original condition when the need for the temporary roadway is resolved.

In some cases, it is possible to take advantage of existing infrastructure for the temporary road. This could include upgrading an existing minor road, making use of an old roadbed, or following an abandoned rail line or a utility corridor. For example, Figure 22 features an east-west road near the middle of the image. Before the freeway was built, the road continued to the east, and the old roadbed is intact, as shown in Figure 23. If the freeway were cut off by an adverse event south of the area shown in Figure 22, one way to restore access temporarily could be to use the old roadbed to connect the east-west road to the freeway.



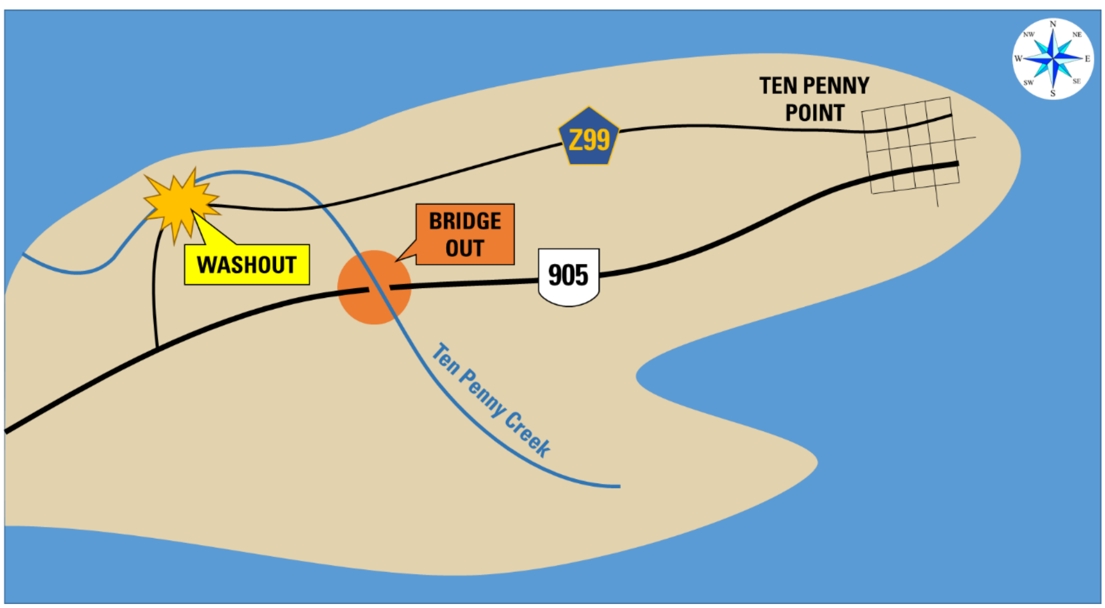
WorldWind Explorer, © 2016–2021, Bruce Schubert, MIT License

Figure 22. Stub ends of existing secondary roads can sometimes provide emergency access to major facilities, which can help minimize the need for new construction.

© 2021 Google Earth

Figure 23. At the site shown in Figure 22, the old east-west roadbed is somewhat overgrown but remains visible from the freeway.

Site Planning Example. Figure 24 is a stylized illustration of a coastal community that is vulnerable to weather-related incidents. While the State Highway 905 bridge over Ten Penny Creek is being removed and rebuilt, the village of Ten Penny Point is relying on its secondary access via County Highway Z99. If a storm causes a washout along Z99, the community will become inaccessible by road.

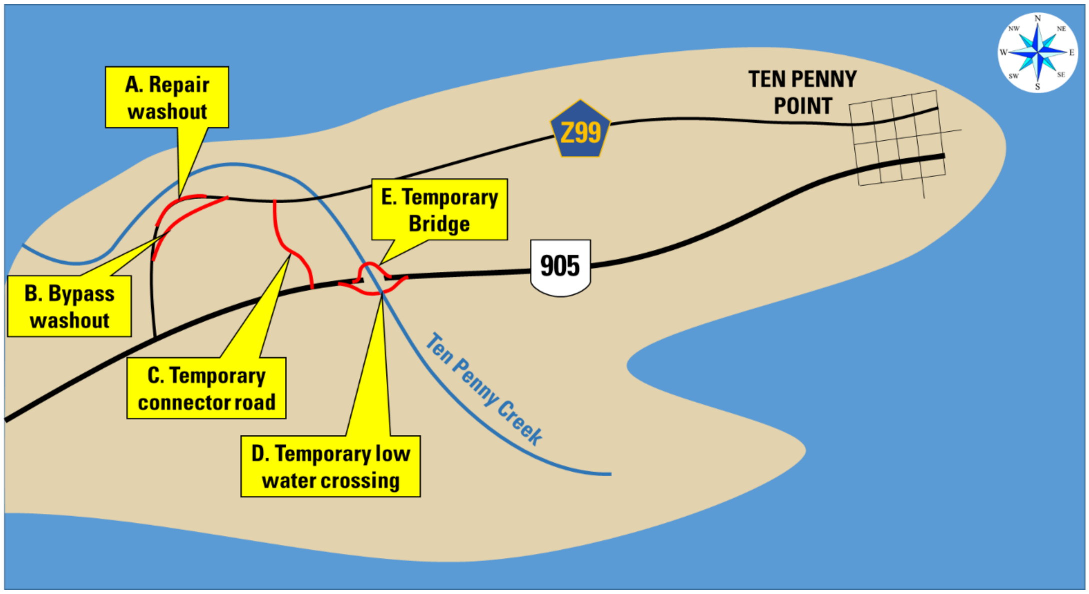


Source: FHWA

Figure 24. Hypothetical example of a community that is vulnerable to adverse events during road construction.

As Figure 25 shows, in principle there are five options for restoring access to the village:

- Replace the washed-out section of County Highway Z99
- Build an expedient east-west bypass around the washout
- Build an expedient north-south road west of Ten Penny Creek to connect County Highway Z99 with State Highway 905
- Build a temporary low-water crossing of Ten Penny Creek parallel to the State Highway 905 bridge
- Build a temporary bridge across Ten Penny Creek



Source: FHWA

Figure 25. Potential solutions for expedient restoration of access.

Site conditions and the nature of the emergency will dictate which of these options is the most feasible. For example, if Ten Penny Creek is in a deep gorge, it might be impractical to build a low-water crossing or temporary bridge. After ruling out these two options, a designer could use satellite imagery, topographical maps, and field reconnaissance to consider which of the other expedient roadbuilding options is the most suitable: restoring the washed-out section, building an east-west bypass, or building a north-south connection between State Highway 905 and County Highway Z99.

A number of factors will influence the selection of the expedient accommodations and their alignment. These include but are not limited to the following:

- Current status of the construction project, i.e., how much infrastructure has already been removed or built and the resulting ease or difficulty of installing an expedient road on the main highway right-of-way
- Extent of damage to other existing roadway infrastructure
- Availability of land where an expedient road can be built
- Amount of time available for constructing the expedient road
- Anticipated vehicle types, traffic loads, and amount of traffic
- Amount and skill level of available personnel
- Type and condition of available equipment

- Terrain, vegetation, and social and environmental conditions along the potential alignments for the expedient road
- Type, quality, and quantity of available construction materials and the ease of obtaining and time required to obtain additional materials
- Required size and number of retaining walls, culverts, drainage swales, or other ancillary structures

Right-of-Way/Real Estate Considerations

From a property rights perspective, it is preferable to locate expedient roads on publicly owned land or on property where right-of-way can be obtained through temporary easements from a manageable number of private owners. In preplanned situations, the required temporary easements or rights-of-way could be obtained as part of the overall real estate acquisition process. In emergencies, some landowners may be willing to allow their property to be used temporarily, especially if doing so benefits their own situation.

Many states have statutes or case law that allow the public use of private property in emergencies. For example, police officers chasing a suspect do not need to obtain a landowner's permission to follow the suspect onto private property. Entry for temporary emergency construction on private property is a complex area of the law, well beyond the scope of this document. The ability to enter upon private property may also be affected by the context of the situation, such as whether a state of emergency has been officially proclaimed. Agency legal departments should be consulted for situationally specific advice.

If private property owners are willing to allow construction of a temporary road on their land to mitigate an emergency, it is highly desirable for the consent to be made in writing. Typically, this would be done using the agency's standard right-of-way (or temporary limited easement) documents. In many cases, it will be desirable for the document to mention the "overbearing necessity" of using the private property to protect public safety. (The phrase "overbearing necessity" appears in some of the important judicial precedents related to the public use of private property in emergencies.)

Removal of Temporary Facilities

An expedient road is not a permanent facility and is typically implemented using emergency authority that bypasses the normal requirements for public consultation and environmental review. As a result, it is important to ensure that the appearance, function, and management of the roadway do not convey a false sense of permanence.

When the facility is no longer needed, there will likely be a need to remove road surfacing and structures, backfill ditches, replant disturbed areas with suitable vegetation, and so forth. To the extent possible, the roadway should be planned for ease of removal. For example, the use of materials that decay naturally can help minimize the cost and complexity of restoring the site to substantially its original condition.

As noted earlier, preconstruction site photos should be saved to help guide removal and restoration of the site. Having good documentation can also help avoid disputes with landowners and resource agencies, who might otherwise want the site improved beyond its prior condition.

Materials for Expedient Road Construction

The selection of expedient roadbuilding materials is usually a function of the intended function of the road and the types of materials that are readily available. As discussed in more detail in Chapter 2, applicable materials include gravel, wood chips, slurry or other controlled low-strength material (CLSM), soil, bagged aggregates such as sand or gravel, corduroy (logs), prefabricated matting systems, and possibly asphalt. Figure 26 through Figure 30 show examples of the use of gravel, prefabricated matting systems, wood chips, bagged aggregates, timber planks, and corduroy in expedient or temporary roads, and Table 1 compares different materials in terms of several criteria. Site conditions and circumstances should be taken into consideration; for example, plastic mats are not a good choice near an active forest fire.

Figure 26. Gravel over geotextile (foreground) and plastic mats (background) used to build a temporary road.

John Suscovich / https://www.youtube.com/watch?v=7NRK7VtAj3o

Figure 27. Road surfaced with wood chips after one year of use by light commercial traffic.

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Figure 28. Bagging gravel, sand, or soil improves its stability, allowing a strong road to be built without heavy equipment. The bags can be stacked to build box culverts and retaining walls.

© Qyd / Wikimedia Commons / CC BY-SA 3.0

Figure 29. Timber plank road built over unstable soil.

Millsy / Wikimedia Commons / Public Domain

Figure 30. Placing corduroy over unstable soil with a tracked excavator.

Table 1. Comparison of rapid response construction techniques and materials.

Technique	Quick to Build	Easy to Build	Materials Easy to Obtain	Equipment easy to obtain	Environmental Impact	Durability	Cost	Remarks
Roads								
Earthen path on native soil	●	●	◐	◐	●	○	●	Ⓐ
Gravel road on gravel base	●	●	◐	◐	◐	◑	●	
Gravel road on portland cement stabilized base	◑	◑	◑	◐	◐	◐	◐	Ⓑ
Gravel road on acrylic polymer stabilized base	◐	●	○	◐	◐	◑	◑	Ⓒ
Gravel road on geogrid stabilized base	◐	●	○	◐	◐	◑	◑	Ⓓ
Bagged-aggregate road building technique	○	●	●	●	◐	●	●	
Temporary wood chip road	●	●	●	◐	●	◑	●	Ⓔ
Temporary timber plank road	○	◑	◑	◐	●	◑	◑	Ⓕ
Woodchips in geotextile with gravel surface	◐	●	◐	◐	◐	◐	●	
Temporary road on plastic mats	◐	◐	○	◐	●	◑	◑	Ⓖ
Thin asphalt on gravel base	◐	◐	◑	◑	◑	◑	◑	
Thin asphalt on portland cement stabilized base	○	◑	◑	◑	◑	◐	◑	
Thin asphalt on acrylic polymer stabilized base	◑	◐	○	◑	◑	◐	○	
Thin asphalt on geocell/geogrid stabilized base	◑	◐	○	◑	◑	◐	○	
Bridges, Bridge Alternatives, and Culverts								
Culvert - bagged-aggregate technique	◑	●	●	●	◐	●	●	
Culvert - pipe	◐	◐	◑	◐	◐	◐	◑	
Low-water crossing - bagged-aggregate technique	○	●	●	●	●	◐	●	
Low-water crossing - concrete surface	○	○	◐	◐	○	●	◑	
Low-water crossing - gravel	◐	◐	●	◐	◑	◑	●	
Low-water crossing - plank treads	◑	◐	◑	◐	◑	◑	◑	
Portable segmental bridge	●	●	○	◐	◐	●	○	
Temporary wood plank bridge deck	◑	◑	◑	◐	●	◑	◑	
Pedestrian Accommodations								
Temporary pedestrian walkway - gravel surface	●	●	●	◐	◐	◑	●	Ⓗ
Temp. pedestrian walkway - thin asphalt surface	◐	◐	◐	◑	◑	◐	◑	
Temp. pedestrian walkway - timber and rope	◑	◐	●	◐	●	◐	◐	
Temp. pedestrian walkway - timber puncheon	○	◑	●	◐	●	●	◑	Ⓖ

Legend

● Very Good ◐ Good ◑ Fair ○ Poor/Inconsistent

Comments

Ⓐ Suitable only for low traffic volumes.
Ⓑ Rototiller or agricultural disk can be used to mix road base with dry cement.
Ⓒ Polymer can also be retrofitted to strengthen an existing gravel road.
Ⓓ Chain link fence sometimes used as an expedient alternative to geogrid.
Ⓔ On weak soils, consider using timbers over crossties (like a railroad track).
Ⓕ Natural decay may reduce/eliminate the need for removal of wood chip road
Ⓖ Plastic mats are available from several vendors.
Ⓗ Gravel must be very well compacted to serve wheelchair traffic.

Construction Overview

Since this document is written primarily from a traffic management perspective, the process of constructing an expedient road is not presented in detail. Additional information and guidance can be found in Watershed Management Field Manual: Road Design and Construction in Sensitive Watersheds (FAO 1998).

Chapter 2. Surfacing Options for Expedient Roads

Introduction

As discussed in Chapter 1, expedient roads such as that shown in Figure 31 are generally built to handle limited volumes of low-speed traffic, often with an emphasis on providing basic access for pedestrians and light wheeled traffic such as ATVs. Often the expedient road has a limited service life, usually a year or less. In other situations, it can serve as a pioneer road that is later converted into a more durable temporary road to support disaster recovery and rebuilding, as shown in Figure 32.

Figure 31. Expedient road bypassing a bridge washout.

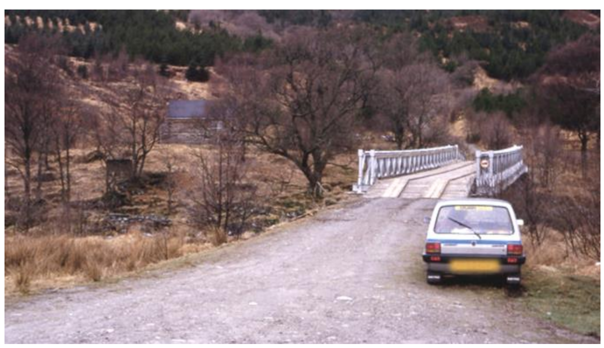


Figure 32. Temporary road and temporary bridge.

The selection of surfacing materials for an expedient road is usually based on the intended function and service life of the road and the types of materials that are available at or near the site. Site conditions and circumstances should also be taken into consideration. For example, plastic mats such as those shown in Figure 33 are not a good choice near an active forest fire. The expected duration of the emergency situation is also a consideration. For example, if the road will be needed for only a short time, the use of natural and biodegradable materials will make it easier to restore the site to its original condition when the expedient road is no longer needed.

Figure 33. Gravel over geotextile (foreground) and plastic mats (background) used to build a temporary road.

The following sections summarize various surfacing options for expedient roads.

Gravel

Gravel or crushed stone is often the most appropriate material for an expedient road due to its durability, low cost, and availability in most parts of the United States. In general, an open-graded gravel (a mixture of small and large stones) will result in a more stable road surface than gravel with uniformly sized stones. Compaction is usually more successful if the gravel is angular (not rounded), especially if the compaction is to be done by hand or with small equipment. Figure 33 shows a portion of a temporary road constructed using gravel over geotextile.

Advantages:

- Gravel is relatively inexpensive in most areas of the United States.

Disadvantages:

- Hauling and placing gravel can be problematic if equipment is unavailable or the site is difficult to reach.
- Post-incident gravel removal and site restoration can be expensive and time-consuming.
- Gravel is not available in all areas, and sometimes the local gravel is low quality.
- Loose gravel is difficult for people with disabilities to traverse.

Wood Chips

Wood chips are routinely used for temporary and permanent pedestrian paths, such as the trail shown in Figure 34. Several practitioners have reported success with using a thick layer of wood chips to build farm roads and light-commercial driveways, such as the road shown in Figure 35 (Lewis 2016). In the mining industry, wood chips have been used as a surface treatment to control dust on haul roads, though in this application the wood chips require periodic replacement due to breakdown under heavy axle loads (Williams 1979).

Figure 34. Trail surfaced with wood chips, New York City.

John Suscovich / https://www.youtube.com/watch?v=7NRK7VtAj30

Figure 35. Road surfaced with wood chips after one year of use by light commercial traffic.

It is possible to use wood chips for deep fills. In the forestry and mining industries, this has proven to be an effective way to build roadway embankments across marshlands (Bowman et al. 1987). Although heavy trucks sink into the chips about 4 to 6 in., the chips rebound after the load passes. The cost of materials is about the same as for soil fills, but with reduced maintenance costs and less environmental damage. Many environmental agencies prefer deep wood chip fills to soil or aggregate fills for temporary forestry roads because the chips decay naturally after the logging operations are complete (Hrůza et al. 2016). Wood chips exposed to air decay over a period of several years; if the chips are submerged in water, the decay takes about 30 years (Bowman et al. 1987).

Wood chips enclosed in geotextile fabric can be used to build a durable road. As described in Hrůza et al. (2016), an 8 in. layer of wood chips that is enclosed in geotextile and surfaced with about 3 in. of gravel can be used to build a semipermanent road over weak soil. This is faster and easier than building a corduroy road (corduroy roads are described later in this chapter).

Advantages:

- Wood chips are often available locally at little or no cost. Utility companies, municipal public works departments, and park districts often have large stockpiles from tree maintenance.
- Wood chips decay naturally. This may eliminate the need to remove the temporary roadway and can help minimize erosion and other undesirable environmental impacts of the expedient road.
- Wood chips can be used to build deep fills over waterlogged soil.
- Wood chip roads naturally limit traffic speed due to the somewhat spongy surface.

Disadvantages:

- Wood chips that are in direct contact with heavy wheel loads will require periodic replacement.
- Geotextile fabric is required to stabilize the wood chips in semipermanent applications.
- Exposed, dry wood chips are not suitable for fire zones.
- Large, loose wood chips may be difficult for people with disabilities to traverse; chip binders (usually spray-applied) are commercially available.

Controlled Low-Strength Material

CLSM is also referred to as concrete slurry, flowable fill, lean-mix backfill, or other terms. Unhardened CLSM is self-leveling, with approximately the same texture as a milkshake, as shown in Figure 36. After hardening, it forms a firm surface similar to hard-packed dirt, as shown in Figure 37.

American Coal Ash Association 2003

Figure 36. Discharging CLSM from a mixer truck.

S. Birchall / North Dakota State University

Figure 37. Flatwork paving with CLSM.

CLSM is produced from the same ingredients as concrete: water, aggregate, portland cement, and fly ash. For CLSM, only a little cement is used, resulting in a compressive strength of 100 to 200 psi. In comparison, structural concrete is usually designed to achieve at least 3,000 psi. CLSM with a strength of 150 psi or less can be removed with hand shovels or a backhoe. The cure time ranges from 1 to 8 hours depending on the mix design and ambient temperature.

CLSM surfacing can be used in relatively flat areas. For expedient applications, sandbags could be used as the "formwork." In addition, CLSM is self-compacting, making it useful for backfilling trenches and holes, including narrow openings that are difficult to fill with other materials.

Soil or Sand

There are many types of soil. Soils containing organic material are often called black dirt. They are soft and weak, tend to rut easily, are slippery when wet, and tend to settle or compress severely under load. As a result, this material is undesirable for carrying any but the lightest traffic and should be removed if possible. Nevertheless, it is worth noting that a black dirt road with moderate load-bearing capacity can be constructed if a soil confinement system is used, such as the geocell grid shown in Figure 38 or the earth bag construction shown in Figure 39. The black dirt road will require frequent maintenance to remove ruts and add new material as compaction occurs.

United States Marine Corps

Figure 38. Geocell grid helps stabilize gravel, sand, and soil by limiting lateral movement.

Community Road Empowerment, © 2014–2020 | Core Kenya

Figure 39. Bagging gravel, sand, or soil improves its stability, allowing a strong road to be built without heavy equipment. The bags can be stacked to build box culverts and retaining walls.

Most parts of the United States have inorganic soil below the black dirt. This is often called brown dirt or red dirt and is usually a mix of clay, silt, sand, and gravel. Its mechanical properties and stability are generally much better than those of black dirt. Brown/red dirt is routinely used for building low-volume rural roads, and the techniques for doing so are well documented. The following are two useful guides:

- Watershed Management Field Manual: Road Design and Construction in Sensitive Watersheds (FAO 1998)
- Low-Volume Roads Engineering: Best Management Practices Field Guide (Keller and Sherar 2003)

There are several techniques for strengthening and improving the stability of dirt roads:

- Binders such as calcium chloride, portland cement, or acrylic resin can be mixed with the dirt to improve cohesion, loading capacity, and durability.
- Geocell grid and geotextile, shown in Figure 38 and Figure 40, respectively, improve loading capacity by helping prevent the material from moving sideways under wheel loads.
- The bagged-aggregate technique (also called do-nou) is another way to control lateral soil movement. An example of the use of this technique is shown in Figure 39. The bags of aggregate are normally small enough to carry by hand and can be compacted with hand tools or a small vibrating-plate compactor. Bags of soil (or preferably gravel) can also be stacked and tamped to build box culverts and retaining walls. For more details, see Chapter 3.

Matthew Gilbert / U.S. Army

Figure 40. Geotextiles separate soil layers and can be wrapped to form a tube that controls lateral soil movement.

Advantages:

- Dirt is usually available close to the site at a low cost.
- Techniques for building dirt roads are well documented and well known.

Disadvantages:

- Dirt is not as strong or durable as some of the other materials for constructing expedient roads.
- Dirt roads are vulnerable to washouts and erosion.
- Dirt roads require frequent maintenance to correct rutting.
- Removal and restoration of an expedient dirt road can be time-consuming, and it can be difficult to control erosion while vegetation is reestablished.
- The addition of a binder may be needed to make the surface suitable for people with disabilities.

Plank/Panel Systems

A wide range of timber planks, prefabricated road panel systems, and mats are commercially available. Examples of these materials are shown in Figure 41, Figure 42, and Figure 33, respectively. Some are designed for very heavy loads, while others are intended mainly for pedestrian traffic. Various materials are used, including wood, plastic, aluminum, steel, and concrete. With the exception of plastic mats, most systems require lifting equipment such as a backhoe, excavator, or crane for installation and removal. Suitability for people with disabilities varies by system.

Figure 41. Timber plank road built over unstable soil to allow heavy equipment to reach a drilling site.

Figure 42. Temporary road assembled from prefabricated mats.

Advantages:

- Installation and removal is easy if suitable equipment is available.
- Removal generally has relatively modest environmental impact after site vegetation is restored.
- Systems are sometimes available for rental.

Disadvantages:

- Transporting panels to the site can be difficult in emergency situations.
- Plank/panel systems work best on smooth, level sites.
- Some systems have a limited ability to accommodate horizontal curvature.
- Some systems are slippery when wet.
- Many systems require heavy equipment for installation.
- Wood or plastic panels may be unsuitable for use in fire zones.

Corduroy

Invented more than 4,000 years ago, the corduroy road building technique is still used in forestry and wartime military applications. Its main purpose is to allow heavy vehicles to traverse an area with unstable soil such as a marsh or bog. As shown in Figure 43, corduroy consists of hundreds of logs laid side by side, perpendicular to the direction of travel (usually alternating the wide and slender ends of the logs). To smooth the riding surface, the logs are covered with a layer of branches or geotextile and then with soil or gravel, as shown in Figure 44.

Millsy / Wikimedia Commons / Public Domain

Figure 43. Placing corduroy over unstable soil with a tracked excavator.

Millsy / Wikimedia Commons / Public Domain

Figure 44. Corduroy road after backfilling with earth.

As noted earlier, if suitable materials are available, an overall level of performance similar to that of corduroy can be obtained using wood chips enclosed in geotextile fabric. The wood chip technique allows roads to be built more quickly and makes use of waste materials instead of whole logs.

Advantages:

- Corduroy allows a strong road to be built over weak soil or marshland.
- Timbers can last a long time if they are submerged.

Disadvantages:

- The technique requires cutting and debranching a very large number of trees.
- Corduroy roads are slow and labor-intensive to build.
- Corduroy is difficult to remove.
- The construction of corduroy roads has potential long-term impacts on drainage, vegetation, and wildlife.
- If geotextile is available, a wood chip road can provide similar functionality with far less labor, material, and environmental impact (Hrůza et al. 2016).

Asphalt

Where suitable materials and equipment are available, an expedient road can be surfaced with asphalt, as shown in Figure 45. Typically, the asphalt is placed in a relatively thin layer (2 to 4 in.).

Figure 45. Temporary road with asphalt pavement.

Advantages:

- Asphalt provides a smooth driving surface.
- Asphalt allows higher traffic speeds than other expedient surfacing materials.
- Roads surfaced with asphalt are easy for pedestrians with disabilities to traverse.

Disadvantages:

- Asphalt is relatively expensive.
- An asphalt surface may encourage traffic speeds that are inappropriate for site conditions.
- Asphalt may suggest a degree of permanence that is viewed unfavorably by residents or environmental agencies.

Chapter 3. Bagged-Aggregate Construction for Traffic Management

Introduction

In situations where construction equipment is unavailable to construct expedient roads, the bagged-aggregate technique allows for durable road construction and repair using nothing but hand labor, gunny sacks, local aggregate such as gravel or sand, and basic construction tools. It is an extension of techniques originally used for building temporary flood controls and military bunkers and can also be used to build retaining walls, box culverts, retention ponds, and dikes. This technique is also called earthbag construction, dōnō, or do-nou.

Although bagged-aggregate construction is labor-intensive, the technique is very simple (able to be done by unskilled workers or volunteers if necessary). In some cases, this will allow restoration of traffic long before outside help can reach a stricken area. The sequence of photographs in Figure 46 outlines the bagged-aggregate construction process.

(a) Placing lower layer of a bagged-aggregate road

(b) Spreading gravel interlayer

(c) Placing and hand-tamping upper layer

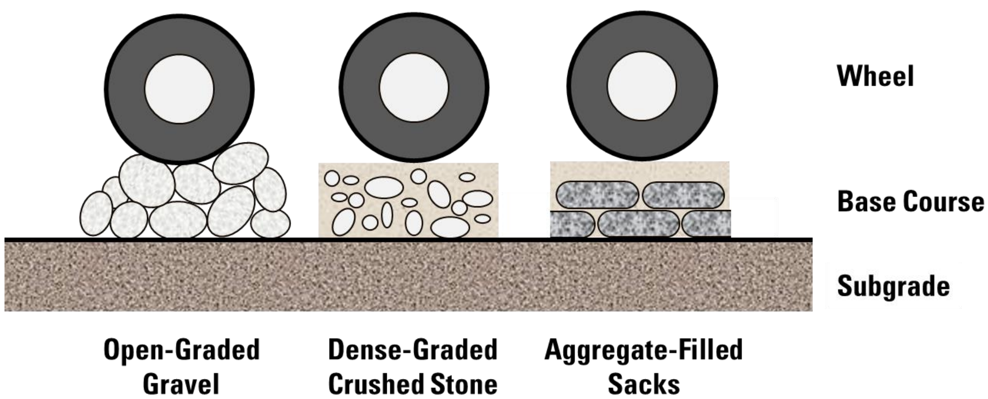
(d) Nearly completed road

Figure 46. Road construction using bagged-aggregate technique.

Two overlapping layers of aggregate-filled polypropylene sacks are typically used. Limited low-speed traffic can run on a single layer of bags, or even on bags placed only in the wheel tracks. This can allow essential vehicles to pass while the rest of the road is being built.

Multiple layers of bags can be stacked to fill low spots, washouts, or gullies. Aggregate bags can also be placed in potholes for spot repairs. Aggregate bags placed over logs have been used successfully as bridge decks for pedestrian traffic, similar to the box culverts described later in this chapter (Fukubayashia and Kimura 2014). Other potential applications for aggregate bags include retaining walls, the running surface for a low-water crossing (for example, fording a shallow creek to bypass a bridge closure), the lining for a drainage channel that is subject to erosion by fast-moving water, stormwater retention ponds, and dikes.

In general, the bagged-aggregate technique is suitable for road building on flat terrain, sags, and gentle slopes (Fukubayashia and Kimura 2014). The bags spread and distribute wheel loads, creating a firm driving surface even if the subgrade is relatively soft, as illustrated in Figure 47. If the situation allows, existing topsoil should be removed so that the bags can be placed on a subgrade that is free of black dirt or other organic materials. The typical excavation depth is approximately 4 in. (10 cm) for one layer of aggregate bags, 8 in. (20 cm) for two layers, or 12 in. (30 cm) for three layers (JICA n.d.). If there is a shortage of materials or labor, the excavation might be limited to the wheel tracks.



After Fukubayashia and Kimura 2014

Figure 47. Comparison of road building techniques.

While it is possible for vehicles to drive directly on the aggregate bags for a short time, a surface course of crushed stone, gravel, dirt, or wood chips should be placed over the bags for durability. Without a surface course, localized rutting will occur; this will affect traffic speeds but usually does not damage the road structure. Moreover, ultraviolet rays from sunlight will gradually degrade uncovered bags, resulting in fraying and loss of strength. Woven polypropylene bags that are protected from sunlight and direct wheel contact can last for decades.

For steeply sloped roads that will be used for a long time, the surface course can be stabilized to prevent erosion; this is particularly helpful if the surfacing material is sandy. Stabilization involves mixing the surfacing aggregate with a binder such as portland cement at the time of construction or coating the surface with acrylic polymer, chip seal, or otta seal at a later date.

Construction Overview

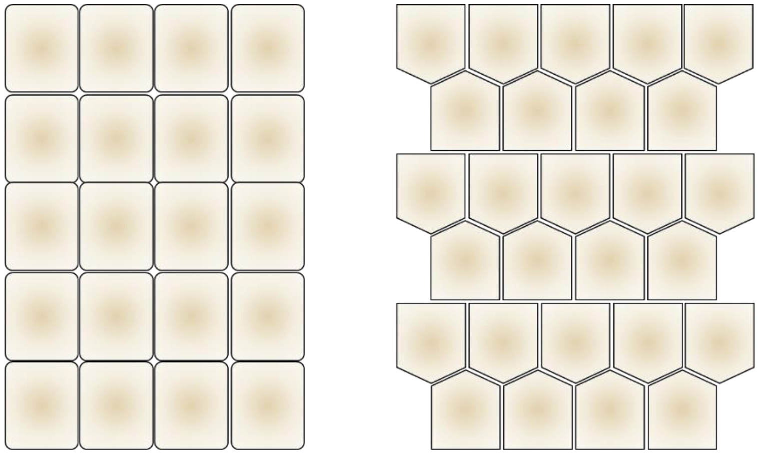
This section provides an overview of the bagged-aggregate construction process to help clarify the role of this technique in managing traffic after an adverse event.

Materials. The sacks typically used to make emergency flood control sandbags are well suited for this type of roadbuilding. These sacks usually measure approximately 14 by 24 in. when empty (FEMA 2013). They are available from various online vendors and are sometimes kept in reserve by state and local emergency management agencies. When three-quarters full, each sack holds about 4¼ gal of aggregate and weighs about 50 lb, making it generally light enough for one or two people to carry and place. Grain sacks can also be used but will be too heavy for one person to lift unless they are only partially filled.

Although the bags used for this type of construction are usually made from woven polypropylene, they are sometimes informally referred to as burlap bags or gunny sacks. Traditional burlap/gunny is a coarse fabric made from natural plant fibers such as hemp, jute, or sisal. The preferred material depends on the application. Synthetic fiber bags are good for semipermanent or permanent applications. Natural fiber bags, shown in Figure 51b, will gradually decay, which can simplify site restoration in short-term applications.

The preferred aggregate materials are crushed stone with fines (also known as dense-graded or breaker run stone), gravel (preferably a mix of large and small particles), sand-gravel mixtures, sand-clay mixtures (preferably 25% to 30% clay), or sand alone. Black dirt (agricultural soil that contains plant/animal matter) can be used if preferred materials are unavailable, but the durability of the road will be reduced.

Installation. After filling with aggregate, the first layer of bags is laid flat on the subgrade. If the bags have been heat sealed or sewn shut, they can be laid in a grid pattern, as illustrated in Figure 48a. If the bags have been closed with cable ties or rope, the tied ends will be somewhat pointed; in this case, the bags should be staggered with the tied ends nested against each other to reduce gaps, as illustrated in Figure 48b.

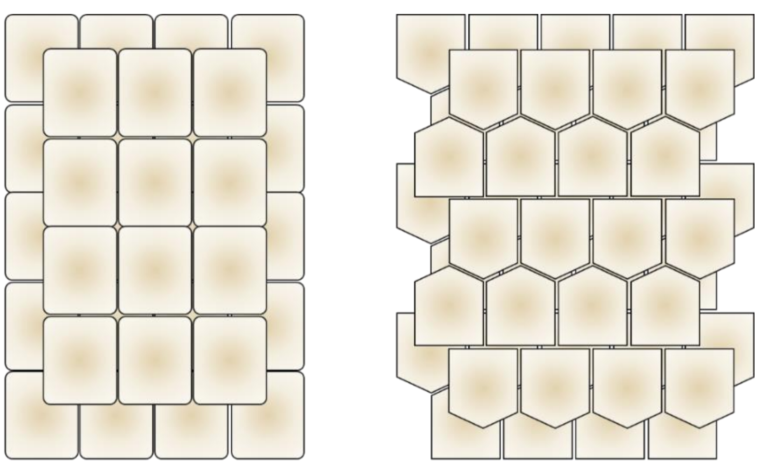


Source: FHWA

Figure 48. Lower-layer layout patterns for bagged-aggregate technique.

A key advantage of the bagged-aggregate technique is that it allows a well-compacted road to be built without a tractor-type soil compactor. The aggregate is consolidated by tamping each bag manually about 10 times, as shown in Figure 52a, or using a portable vibrating plate compactor for faster results.

After the first layer is compacted, the surface is leveled, all gaps between bags are filled with loose aggregate, and a thin layer of aggregate is placed over the bags. The second layer of bags is then placed and compacted. This layer should be offset from the bottom bags by about half the bag width and half the bag height so that the thicker parts of the upper bags line up with the thinner parts of the lower bags, as illustrated in Figure 49. Finally, a running course of aggregate is placed on top of the bags and, if possible, compacted. The preferred thickness of the running course is 2 in. Crushed limestone with fines (dense-graded/breaker run stone) is ideal for the running course, but other materials can be used when necessary.



Source: FHWA

Figure 49. Upper layer layout patterns for bagged-aggregate technique.

For permanent or semipermanent applications, the road can be built on a prepared subgrade and perhaps sealed or paved when equipment and materials become available. As with any road, appropriate drainage should be provided using side ditches or underdrains, and the running course should have a slight cross slope or crown to prevent stormwater from ponding on the road.

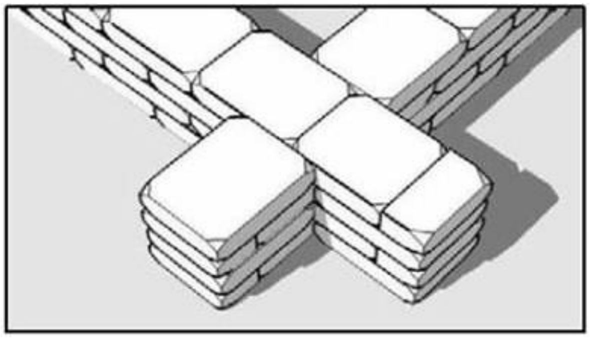
This type of road can be built with very basic tools (shovels and dirt tampers). Construction will go faster if equipment is available to assist with bag filling, hauling, compaction, and gravel spreading. A video at https://youtu.be/FYv3ENYZ_TE illustrates a simple jig made from lumber and plastic pipe to reduce manual filling time to about 15 seconds per bag.

Retaining Walls

When multiple layers of aggregate-filled bags are stacked to build a retaining wall, the bags should be overlapped in a running bond pattern, like brickwork, as shown in Figure 50a. As with any unreinforced retaining wall, the layers should be placed with a slight backward slant (battered), as shown in Figure 50b. In other words, the bottom of the retaining wall should extend out slightly farther than the top. When the wall is built this way, earth pressure tends to straighten the wall, but not so much that the top ends up overhanging the bottom. Small-diameter reinforcing rods can be driven vertically through the bags to connect the layers and enhance stability.

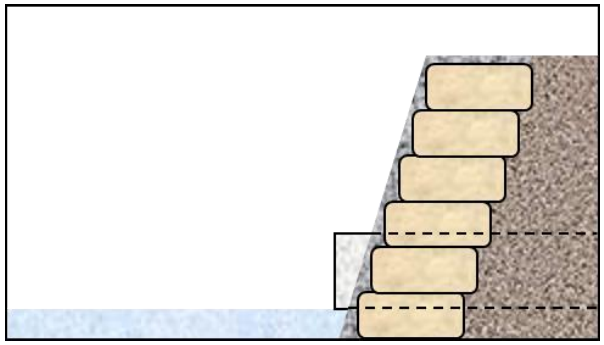
For added strength, retaining walls can be buttressed every few feet, as shown in Figure 50a. The buttress forms a short tee or cross to help resist lateral movement. Barbed wire can also be added between layers for stability, as shown in Figure 50c. Typically, two parallel strands of barbed wire are used between each row of bags, with each strand 3 in. from the edge of the bag. (Nepal Ministry of Urban Development 2017). At the end of each row, the barbed wire should wrap around the end of the last bag and back up to the next layer (Good Earth Global 2018).

For permanent applications, the wall can be covered with portland cement stucco when time permits, as shown in Figure 50d. The stucco helps protect the bags from abrasion and degradation.



Good Earth Global 2018, © 2018 EngineeringforChange.org

(a) Running bond pattern and buttresses (vertical wall).



Source: FHWA

(b) For stability, the bottom of a bagged-aggregate retaining wall should extend out farther than the top (battered wall).

Good Earth Global 2018, © 2018 EngineeringforChange.org

(c) Barbed wire layout (vertical wall).

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(d) Adding stucco for long-term durability.

Figure 50. Details for retaining walls and deep fills.

End Walls and Wing Walls for Pipe Culverts

Aggregate bags can be stacked to build end walls or wing walls for pipe culverts, as shown in Figure 51. The design and construction process is very similar to that of the retaining walls described in the previous section.

Eurobodalla Shire Council

(a) Natural fiber aggregate bags used as culvert end walls for an expedient road.

(b) Natural fiber aggregate bags used as culvert end walls on a permanent equestrian trail.

Figure 51. Aggregate bags used as end walls for pipe culverts.

Box Culverts

Adverse events often result in damage to roadway drainage structures or the need for new drainage structures. If culvert pipe is unavailable or the required water-handling capacity is too large for a pipe, bagged aggregate and timber can be used to build a box culvert. The sequence of images in Figure 52 illustrates the construction of a box culvert (JICA 2017).

(a) Placing and compacting the first layer of aggregate bags to form the culvert wall.

(b) Checking wall height after placing the third layer of bags.

(c) Heavy timbers span the channel.

(d) Completed culvert, showing timbers covered with a layer of aggregate bags and a gravel driving surface.

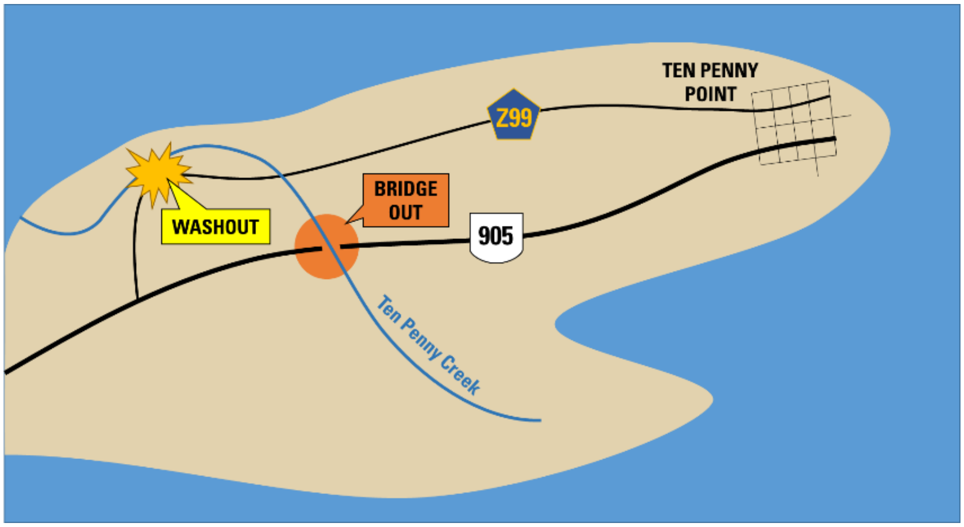
Japan International Cooperation Agency / https://www.youtube.com/watch?app=desktop&v=zcG7cdKXKxU

Figure 52. Hand construction of a small box culvert using timbers and compacted bags of gravel to provide cross-drainage for a road.

After the channel is excavated to the desired width and depth, rows of aggregate bags are placed along each side of the channel to form the culvert walls. Each layer is compacted before the next layer is placed. Partially filled bags can be used for height adjustment. When the desired height is obtained, logs are placed parallel to the direction of travel, spanning across the walls. Smaller cross-timbers are nailed perpendicular to the main logs to limit lateral movement. The cross-timbers are then covered with a layer of aggregate bags, which are compacted and covered with gravel to form the driving surface. Alternatively, the entire deck can be constructed from sawn timber. For permanent installations, the bags forming the side walls and end walls can be covered with stucco. Diagonal braces can be added under the deck for additional stability.

Use Case Example

Situation. To illustrate the use of bagged-aggregate construction, consider the hypothetical example of Ten Penny Point described in Chapter 1. This remote village is located on a peninsula that is ordinarily accessed using State Highway 905, as illustrated in the simplified map shown in Figure 53. The State Highway 905 bridge over Ten Penny Creek was recently demolished in preparation for complete replacement. County Road Z99 was being used as a detour, but heavy rains have severely damaged a section of Z99 that runs parallel to Ten Penny Creek, cutting off all access to the village. Residents and local leaders are concerned about dwindling food, fuel, and medical supplies, and outside assistance will take several days to reach the village due to other incidents. All heavy equipment associated with the bridge project is stranded on the west side of Ten Penny Creek; the only construction equipment available on the east side is the village public works department's dump truck, a small backhoe, and basic tools such as shovels and wheelbarrows.



Source: FHWA

Figure 53. Stylized map of Ten Penny Point.

Possible Intervention. Volunteers fill gunny sacks with a sand-gravel mixture that is available locally. The aggregate bags are loaded onto the dump truck and hauled to the damaged section of County Road Z99. Village public works employees and bridge contractor employees who were staying in the village place aggregate bags to stabilize the damaged road section. Crushed stone from a small local stockpile is then used to surface the roadway, restoring the village's connection to the outside world.

Chapter 4. Temporary Low-Water Crossings

Introduction

Expedient roads often require one or more waterway crossings along the temporary route. Although bridges and culverts are usually the preferred methods for crossing a waterway, there are situations where an LWC (also called a ford) is an acceptable and expeditious way to provide temporary or alternate access to a hard-to-reach area. LWCs accommodate low-volume, low-speed traffic by allowing shallow water to pass over the road surface. They are especially suitable for situations where the waterway is expected to be dry (or nearly so) at the time the temporary route is needed. LWCs can often provide temporary access to a community that would otherwise be unreachable by road or accessible only via a lengthy detour.

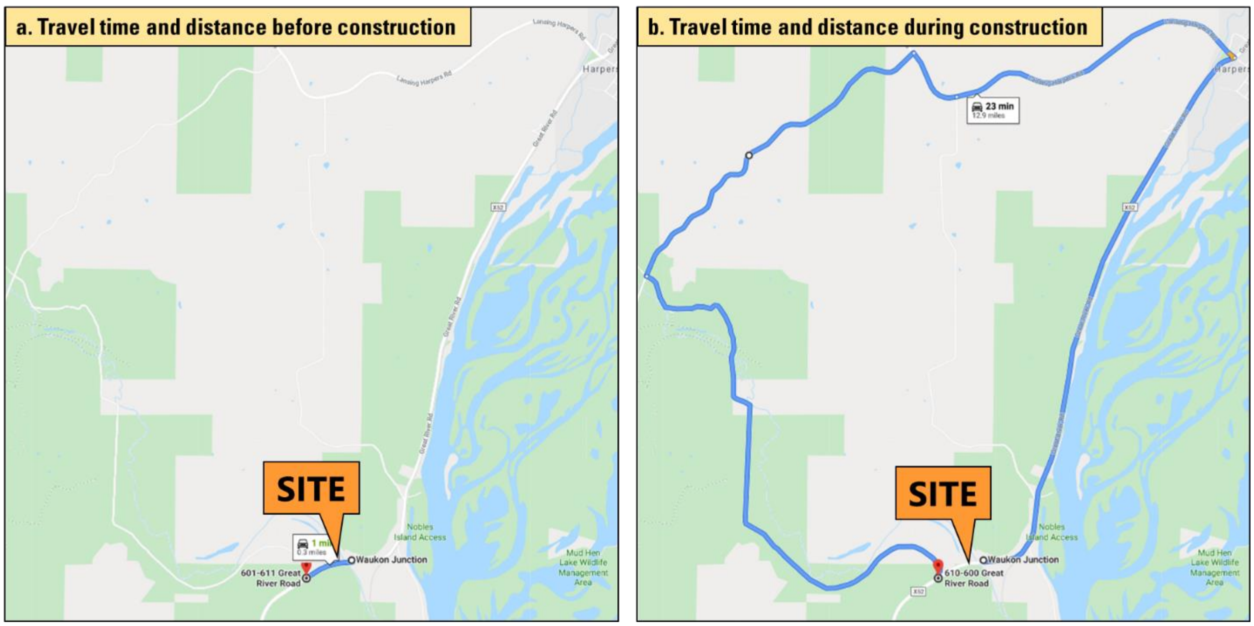
Most LWCs are firm surfaces or shallow culvert-like structures that allow motor vehicles to cross a shallow waterway or dry creek bed. An example is shown in Figure 54. As discussed in more detail in the next section, there are three main types of LWC: unvented fords, gabion fords, and vented fords. Water normally flows over an unvented ford, through a bed of large stones at a gabion ford, or through a set of parallel culverts at a vented ford. After major storms, water flows both through *and* over gabion fords and vented fords. Under normal conditions, the driving surface is often wet at an unvented ford but remains dry at a gabion ford or vented ford.

Figure 54. Unvented LWC and water depth marker.

LWCs can sometimes be incorporated into the overall staging plan for a construction project to make it easier for the contractor to transfer equipment and materials from one side of the jobsite to the other. In the context of this document, their main purpose is to provide temporary access or emergency access to areas that would otherwise be impacted by construction. Thus, there are two main applications for LWCs as a resilience strategy during roadway construction:

1. To provide *planned* access to a remote area that will be affected by construction.
2. To provide *unplanned* emergency access to an area that has unexpectedly been cut off by the combination of road construction and an adverse event.

LWCs are sometimes restricted to certain types of traffic, such as emergency vehicles only. For example, the hypothetical routes shown in Figure 55 illustrate the importance of a temporary LWC that could provide emergency access to part of a community during a bridge replacement project. While general traffic would be expected to use a long detour to avoid the bridge closure, day-to-day use of an LWC bypassing the closure might be restricted to emergency services personnel (police, fire, and emergency medical services) based north of the construction site. This would provide resilience in case the area south of the construction site needs to be reached quickly by first responders.



Base image source: © 2022 Google Maps

Figure 55. Use of a temporary LWC can reduce emergency response time when bridges are out of service.

In this example, the response time from a village to a nearby resort would be about 2 minutes with a temporary LWC (Figure 55, left). Without the LWC, it would take a responder about 23 minutes to reach the resort using back roads (Figure 55, right) or 37 minutes via main roads (not shown).

In the highly floodable area illustrated in Figure 55, installing an LWC might also provide resilience to climate-related disasters by speeding up resident evacuation in case of impending high water. The LWC would effectively provide additional evacuation options: without the LWC, residents north of the construction site would be limited to evacuating to the north, and residents south of the site would only be able to evacuate to the south or west.

Emergency construction of unplanned LWCs can provide temporary access to facilitate rescue and recovery after an adverse event such as a flood or forest fire. In general, this involves building a shallow unvented ford using gravel, timbers, construction mats, or the bagged-aggregate technique.

Types of Low-Water Crossings

There are three main types of low-water crossings.

Unvented fords (also called drifts) are a type of LWC used mainly to cross shallow waterways or dry streambeds, especially sites with limited or intermittent water flow. An unvented ford crossing a shallow waterway is shown in Figure 56. Unvented fords are suitable for waterways without fish and could also be considered in situations where the project will be completed during a time of year when aquatic species are not present at the site. In some cases, gaps can be provided in the driving surface to allow passage of minnows.

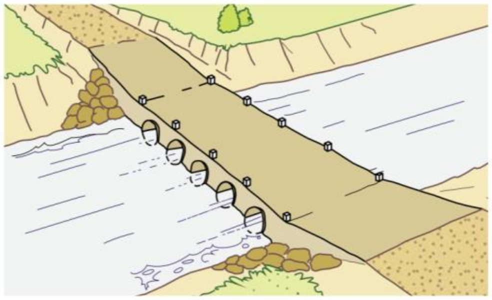
Figure 56. Unvented ford.

Gabion fords are structures comprised of large stones placed in wire-mesh baskets (Clarkin et al. 2006), as shown in Figure 57. Under normal conditions, water flows through the stones; during major storms, water can also flow over the gabion baskets and road surface. This type of LWC does not support fish passage. Gabion fords are particularly useful for crossing broad, shallow runoff channels, such as sheets of water flowing off a hillside or impervious surface.

U.S. Department of Agriculture, Forest Service

Figure 57. Gabion ford on an intermittent waterway.

Vented fords are culvert-like structures, as shown in Figure 58 and Figure 59. Drainage pipes allow water to flow under the road during normal weather. During very wet weather, water flows over the roadway. This keeps traffic out of the water most of the time. Vented fords are particularly suitable for entrenched waterways, or locations where the water ordinarily flows in trench-like channel. Properly designed vented fords can support fish passage, provided that the ordinary water depth in the pipes is sufficient for the species found at the site.



Johannssen 2008 / © 2008 ILO, https://www.ilo.org/asia/publications/WCMS_100216/lang--en/index.htm

Figure 58. Vented ford.

U.S. Department of Agriculture, Forest Service

Figure 59. Upstream side of a vented ford.

Site Selection

LWCs are usually used in locations where the amount of water crossing the roadway cannot be handled with a trench drain (French drain) and the elevation difference between the waterway and the driving surface is not sufficient for a culvert. This can occur, for example, when an expedient roadway needs to be established without building up a roadbed, such as in the scenario depicted in Figure 60.

U.S. Department of Agriculture, Forest Service

Figure 60. Temporary unvented ford built from Jersey barriers and rock backfill in response to a wildfire (California, 2004).

LWCs are usually designed to limit the depth of the water above the driving surface to less than 6 in. during normal weather, which is approximately the wading depth for a typical sedan. Additional information about vehicle wading depth can be found in the Vehicle Wading Depth section at the end of this chapter.

As with all cross-drainage structures, it is important to select the location for the temporary LWC judiciously. Important factors include the slope of the approaches to the waterway, the stability of the streambed, right-of-way availability, and the ease of connecting to existing roads. Other important considerations include the water flow rate and speed (normally and during storms) and the possible need to provide passage for fish and other aquatic species. Examples of candidate locations for unvented, gabion, and vented fords are shown in Figure 61. When locating a temporary LWC, balancing the various considerations may involve some trade-offs. For example, it is often possible to fit an LWC within the existing right-of-way adjacent to a bridge that is being replaced, but the approach slopes might be more favorable at an alternate site.

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(a) Unvented fords can be used to cross shallow, slow-moving water or shallow, dry streambeds.

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(b) Gabion fords are suitable for sites where a road skirts the edge of a hillside with water flowing off in a wide sheet.

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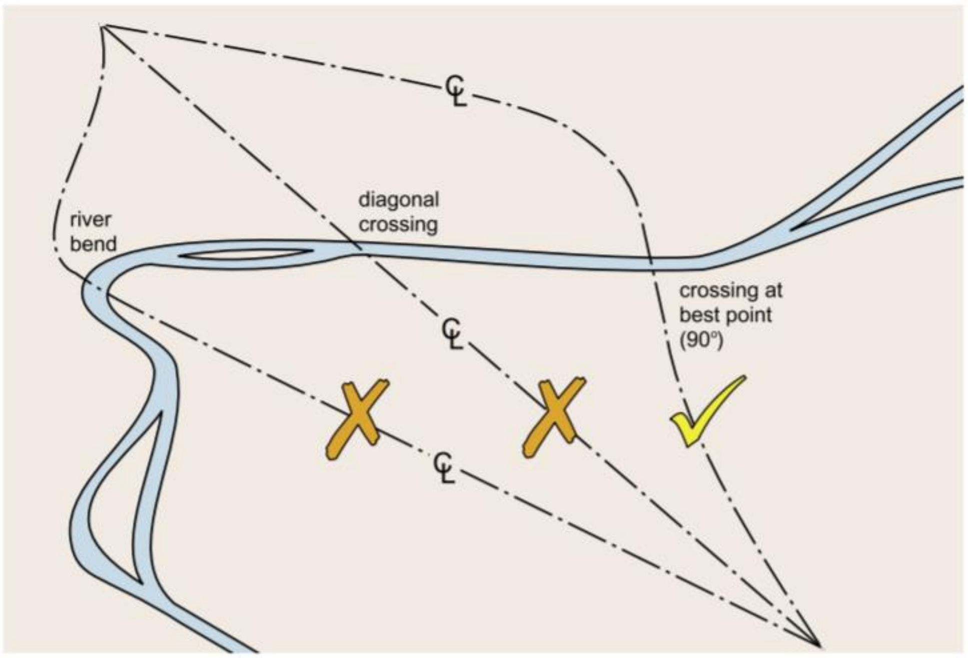
(c) When it is necessary to cross an entrenched channel or provide fish passage, a vented ford, large culvert, or bridge is required.

Figure 61. Matching type of low-water crossing with site characteristics.

Additional site selection criteria are as follows (Johannessen 2008):

- If possible, the angle between the centerline of the road and the flow of the water should be close to 90°, and the site should be on a straight length of the stream (Figure 62).

- Avoid locations where there are signs of scouring or silting.
- A crossing with gentle side slopes is optimal so that the slope of the approach roads can be 5% or less.
- Preferably, the site should be on a straight road.
- The length and elevation of the LWC should match the natural channel so that it does not act as a dam.



Johannssen 2008 / © 2008 ILO, https://www.ilo.org/asia/publications/WCMS_100216/lang--en/index.htm

Figure 62. Preferred waterway crossing angle.

The material used for the driving surface should be selected based on the anticipated velocity of the flowing water and the required service life for the LWC. The following should be considered:

- If a temporary LWC will only be used for just a few weeks and the water flow is relatively gentle, an unvented ford with a gravel running surface could be the lowest-cost option.
- To reduce lateral gravel movement, a gravel running surface can be enhanced with geocell grid, a plastic honeycomb that is expanded on site and backfilled with gravel. The use of geocell grid is shown in Figure 63 and Figure 64.
- For unvented fords, the stability of the driving surface can be enhanced by using timbers or bagged aggregate for the subbase. Since timbers and aggregate bags are slippery when wet, a surface course of gravel, asphalt, concrete, paving blocks, or similar materials is desirable.
- Concrete slabs or pavers are often preferred for permanent unvented fords, especially those prone to scour from flash flooding. Gaps between the slabs or pavers can sometimes accommodate the passage of minnows and other small aquatic species.
- Several brands of proprietary prefabricated tied concrete block revetment are available for unvented fords requiring rapid deployment. These products are often sold in rolls or large mats that consist of a matrix of pre-positioned concrete paver blocks that are permanently attached to a grid of wires, ropes, or bands.

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Figure 63. Geocells can reduce erosion of gravel-surfaced low-water crossings.

U.S. Department of Agriculture, Forest Service

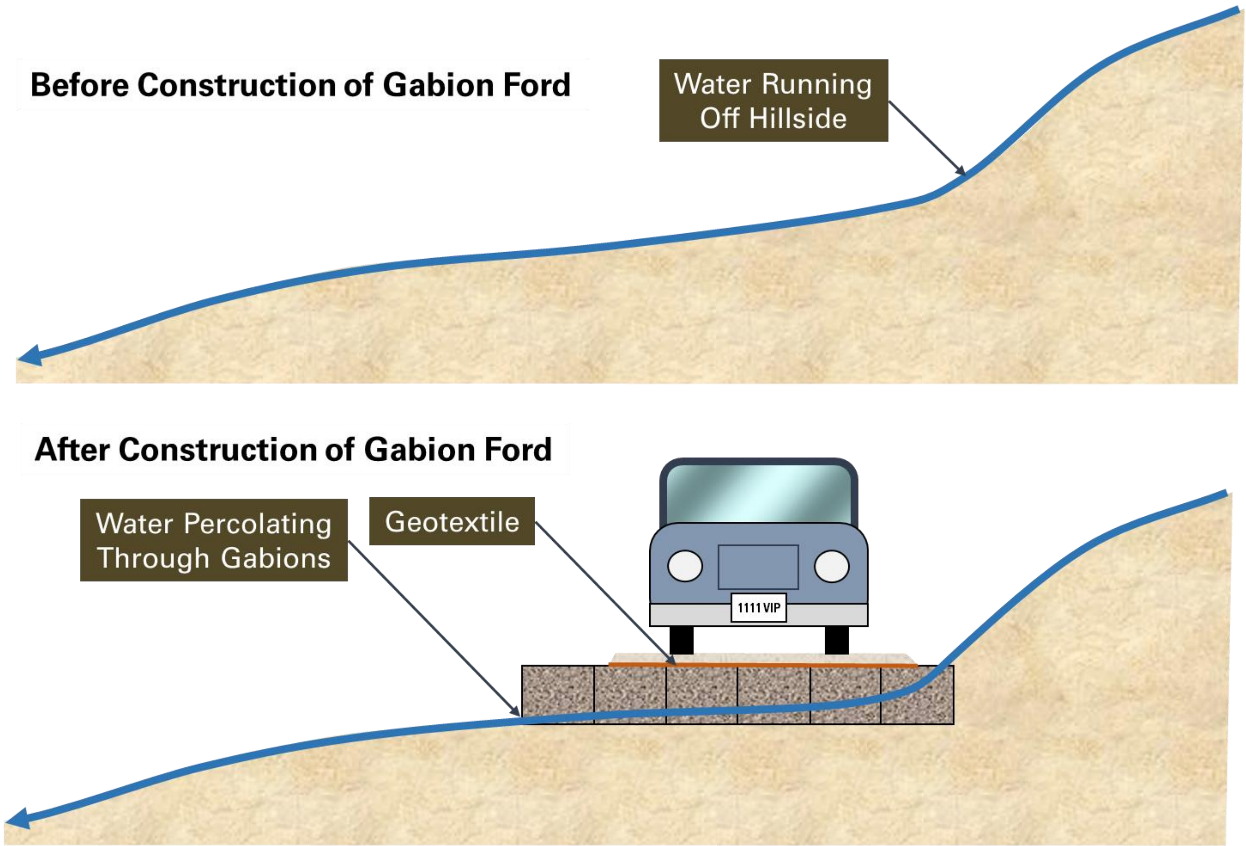
Figure 64. Geocells partially exposed by traffic and water movement.

Figure 65 illustrates a cross section of a typical unvented ford. In most cases, some earthwork is required to achieve a slope on the stream banks that is traversable by motor vehicles. Usually this is done by cutting a portion of the upper bank and using the excavated material to fill the lower bank.

After Jones and Parry 1993

Figure 65. Cross section of a typical unvented ford.

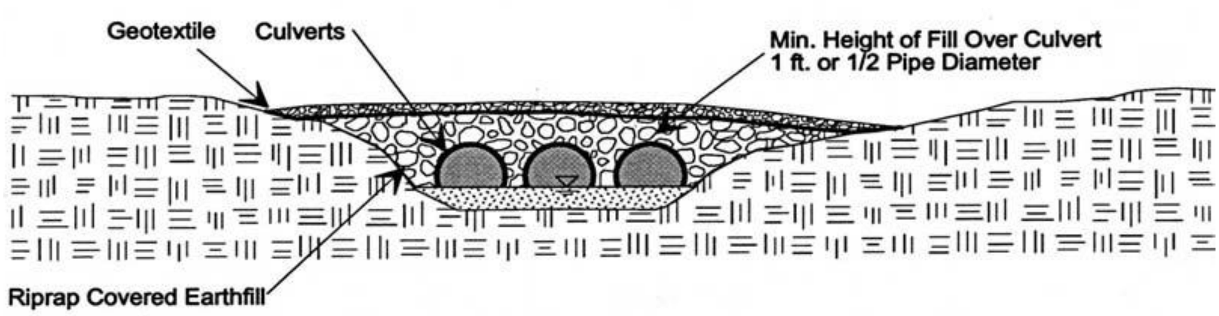
Gabions, shown in Figure 21 and Figure 121, are wire cages or baskets filled with stones. Figure 66 illustrates a hillside before and after construction of a gabion ford. In essence, the gabion acts as a collection device for water running off a hillside. Water enters the uphill side of the gabion as a sheet, percolates through the stones, and is discharged in a sheet on the downhill side of the gabions. This slows and spreads the water, reducing the risk of erosion. A gabion ford thus serves as a simple alternative to catching the runoff in a roadside ditch, piping it under the roadway, and diffusing it on the discharge side.



Source: FHWA

Figure 66. Comparison of hillside before and after construction of gabion ford.

Figure 67 illustrates a cross section of a typical vented ford. Vented fords allow passage of fish, amphibians, and other small aquatic species. For wildlife health, it is desirable to preserve the natural channel as much as possible (Singler et al. 2012). The bottom (invert) of each culvert is ordinarily placed at or very slightly below the elevation of the natural stream bed. Culverts that are undersized, too shallow, or perched above the natural stream elevation should be avoided.



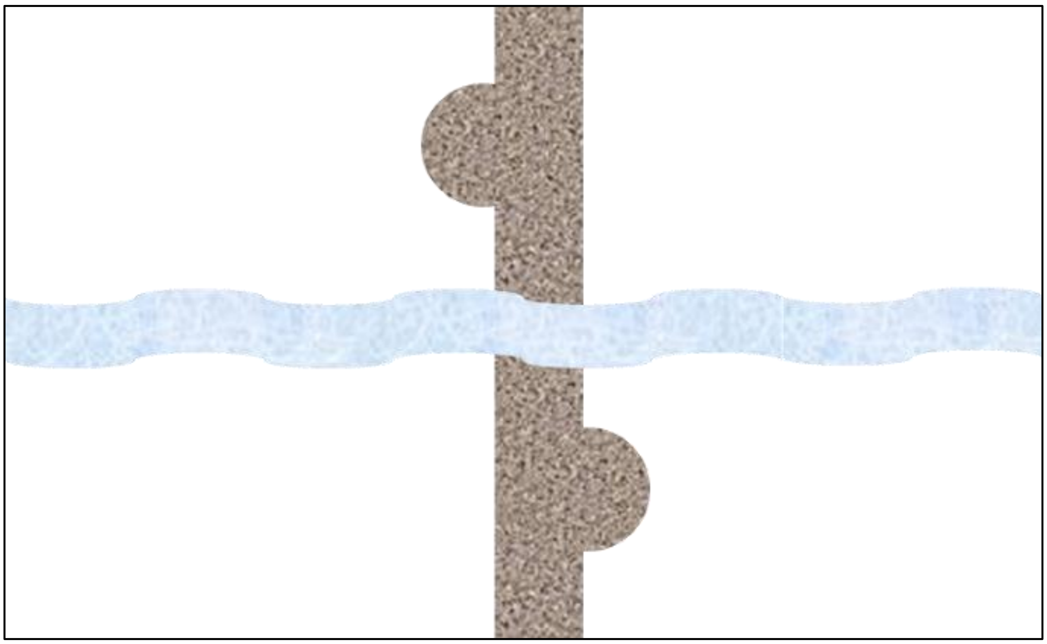
Missouri Office of Administration

Figure 67. Cross section of a typical vented ford.

Traffic Control Devices

If an LWC will remain in service for more than a few days, Type III barricades and appropriate signs should be kept nearby so that the LWC can be closed to traffic in case of heavy flooding or fast-moving water. This equipment includes barricades and ROAD CLOSED (R11-2) signs for both sides of the LWC. ROAD CLOSED AHEAD (W30-3) signs should be provided to give advance notice of the closure on the approaching roadways. A water depth marker, as shown in Figure 54, should also be provided.

Turnarounds (loons) on each side of the crossing, illustrated in Figure 68, can facilitate driver redirection when the water is too deep to cross safely.



Source: FHWA

Figure 68. Turnarounds (loons) can be provided on each side of a low-water crossing to facilitate vehicle redirection when the water is too deep to cross safely.

Special Considerations for Emergency LWCs

When possible, an LWC should be planned as part of the overall design for a construction project. This will provide sufficient time for consideration of all relevant structural, hydraulic, and environmental factors and for the acquisition of any required real estate or temporary access rights.

LWCs implemented as emergency measures are generally installed quickly using low-cost, locally available materials such as gravel. In these cases, agencies generally act under emergency powers that temporarily override some aspects of the design and permitting process. In these situations, it is generally preferable to make sure that the LWC can easily be removed (and the site restored to its prior condition) after the emergency situation has been resolved.

Additional design and legal considerations are discussed in Chapter 1. Also see Clarkin et al. (2006), Jones and Parry (1993), and Singler et al. (2012).

Vehicle Wading Depth

The maximum depth of the water a vehicle can drive through is called its *wading depth*. Examples of vehicles wading through deep water are shown in Figure 69. Wading depth is vehicle-specific and sometimes appears on the manufacturer's specifications sheet. Characteristics such as weight, ground clearance, tire size, and the location of the engine air intake affect a vehicle's wading depth.

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Figure 69. Vehicles wading through deep water.

An automotive industry source reports that typical wading depths (in stationary or slow-moving water) are 6 to 8 in. (100 to 200 mm) for sedans, 8 to 16 in. (200 to 400 mm) for crossovers, and 16 to 30 in. (400 to 760 mm) for most SUVs and pickup trucks (Nissan Motor Corporation 2019).

Public advisories issued by the National Weather Service are more conservative, stating that 6 in. of water will reach the bottom of most sedans, 12 in. of water will float many vehicles, and 24 in. of rushing water can carry away most vehicles, including SUVs and pickup trucks (NOAA n.d.).

Chapter 5. Temporary Bridges and Expedient Culverts

Introduction

Expedient roads often require bridges or culverts to be installed at a time when it is difficult to bring in materials, equipment, or extra personnel. To meet this challenge, several types of temporary bridges and culverts are available that can deployed quickly and assembled from locally available materials. As discussed in Chapter 1, site-specific decisions require consideration of factors such as the degree of urgency, the type of traffic to be accommodated (e.g., pedestrians, ATVs, emergency vehicles), the distance to be spanned, and the available personnel, equipment, and materials.

Application Example

Eurobodalla is a shire (similar to a United States county) on Australia's Pacific coast. It covers more than 1,300 mi^2, mostly national parks and state forests, and is home to about 38,000 people. In December 2019, wildfires destroyed several timber bridges that provided access to rural communities and forest lands.

To restore access quickly, crews installed temporary roads bypassing the fire-damaged structures; one of these roads is shown in Figure 70. This allowed time for temporary bridges on the old alignments to be built, as shown in Figure 71. Later, with state and national financial assistance, permanent concrete bridges at higher elevations, such as those shown in Figure 72 and Figure 73, were installed to improve resilience to future fires and floods.

Eurobodalla Shire Council

Figure 70. Expedient road bypassing a fire-damaged timber bridge (note old pilings at left).

Eurobodalla Shire Council

Figure 71. Expedient road, with temporary bridge under construction.

Eurobodalla Shire Council

Figure 72. Temporary timber bridge facilitating construction of permanent bridge.

Eurobodalla Shire Council

Figure 73. Permanent bridge nearly completed at right; temporary bridge at left.

Temporary Fills and Low-Water Crossings

Temporary fills, such as that shown in Figure 74, are often the most expedient way to establish a temporary driving surface over a waterway. In some regions of the United States, they can serve as a stopgap during the dry season, buying time for the installation of bridges and culverts with hydraulic capacities sufficient to handle the stormwater flows expected in the wetter months of the year. Depending on the locally available materials, temporary fills are usually built from soil or gravel. If available, CLSM, also referred to as concrete slurry or other terms, is sometimes an expeditious way to fill a low area.

Figure 74. Temporary road bypassing a bridge washout.

As discussed in Chapter 4, low-water crossings can sometimes be used in lieu of a bridge. At a low-water crossing (also called a ford), vehicles slowly drive through shallow water that flows across the road. Temporary low-water crossings, such as the one shown in Figure 75, are often an expeditious way for low-volume traffic to traverse waterways with limited or intermittent water flow. These crossings are usually designed to limit the water depth (during normal weather) to 6 in. or less, which can be traversed by most automobiles. If the water is deeper due to a major storm, a crossing might need to be closed to traffic or its use limited to vehicles designed for deeper wading.

U.S. Department of Agriculture, Forest Service

Figure 75. Temporary low-water crossing built from Jersey barriers and rock backfill in response to a wildfire.

Temporary Culverts

The use of temporary culverts such as that shown in Figure 76 can sometimes eliminate the need for a temporary bridge. If culvert pipe is not available due to the emergency, box culverts can be built by stacking bags filled with gravel to create abutments and then bridging the abutments with logs or timbers, as shown in Figure 77. This process is described in more detail in Chapter 3.

© Massachusetts Department of Environmental Protection

Figure 76. Temporary culvert backfilled with gravel.

Japan International Cooperation Agency / https://www.youtube.com/watch?app=desktop&v=zcG7cdKXKxU

Figure 77. Hand construction of a box culvert using timbers and compacted bags of gravel.

Some temporary culverts require headwalls to stabilize embankments and reduce the risk of a washout. Often the headwalls can be built by stacking sandbags, gravel bags, or precast masonry units, as shown in Figure 78 and Figure 79. For greater durability, portland cement stucco can eventually be applied as a facing material to protect the bags from degradation by sunlight.

Eurobodalla Shire Council

Figure 78. Temporary culvert with sandbag headwalls, used to bypass a fire-damaged bridge.

Eurobodalla Shire Council

Figure 79. Temporary culvert with headwalls of large precast masonry units.

Temporary Pedestrian Bridges

The addition of one or more pedestrian bridges can often enhance emergency access to properties and add flexibility during incident response and recovery. Frequently these bridges are also suitable for lightweight wheeled traffic such as ATVs.

The complexity of a pedestrian bridge depends on the width of the required span. For very short spans (such as a narrow backhoe trench), a wooden pallet can serve as a simple and expedient bridge, as long as it is securely positioned and the walking surface has closely spaced boards or is overlaid with plywood. Suitable approaches should be provided, with ramps or fills for any grade changes.

Another quick way to allow pedestrians and light vehicles to cross a small trench is to stack several lengths of plastic water pipe in the trench, as shown in Figure 80 (Blinn et al. 1998). For walkability, the pipes can be covered with a few inches of soil or wood chips. Segments of plastic pipe tethered together with cables or seatbelt webbing can also be used for temporary walkways across ditches, as shown in Figure 81. As with trenches, these can be covered so that pedestrians do not have to walk directly on the pipes.

Blinn et al. 1998 / U.S. Department of Agriculture

Figure 80. PVC pipe bundle for temporary trench crossing.

Blinn et al. 1998 / U.S. Department of Agriculture

Figure 81. PVC pipe bundle crossing for a ditch or small waterway.

For somewhat longer spans, the most expeditious solution is often to fabricate a temporary pedestrian bridge from lumber, as shown in Figure 82. Larger boards such as the 4x4s shown in Figure 83 have been used to build bridges for ATVs and other light wheeled traffic.

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Figure 82. Temporary pedestrian bridge fabricated from lumber.

U.S. Department of Agriculture, Forest Service

Figure 83. Short-span timber bridge for pedestrians and ATVs.

Several vendors offer prefabricated short-span temporary pedestrian bridges, trench covers, and trench plates designed for pedestrian use. Aluminum wheelchair ramps such as that shown in Figure 84 are also well suited for use as short pedestrian bridges; some designs fold or roll up for portability, as shown in Figure 85. Warehouse dock plates and portable truck loading ramps can also be repurposed as short-span pedestrian bridges.

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Figure 84. Prefabricated aluminum wheelchair ramp.

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Figure 85. Roll-up portable wheelchair ramp.

Smooth steel street plates are intended mainly for vehicular use. Their surfaces can be slippery when wet, limiting pedestrian applications. In addition, street plate lifting lugs can be a pedestrian tripping hazard. Since the plates are usually about 1 in. thick, the edges can also be tripping hazards.

Commercial scaffolding systems such as that shown in Figure 86 offer flexibility for pedestrian bridges that require longer spans or 90° bends. Bailey bridges (described below under Temporary Bridges for Motor Vehicles) are frequently used for pedestrian applications requiring spans of 10 to 450 ft.

Ingolfson / Wikimedia Commons / Public Domain

Figure 86. Temporary pedestrian bridge assembled from scaffolding components.

Intermodal shipping containers can be repurposed as pedestrian walkways by cutting an opening in the front end, as shown in Figure 87. Surplus intermodal shipping containers are available in many areas and are often abundant near seaports and rail hubs. Nominal lengths are typically 20, 40, 45, 48, and 53 ft.

Figure 87. Shipping container being repurposed as a temporary pedestrian bridge.

Long-span temporary pedestrian bridges are sometimes constructed on temporary pilings, as shown in Figure 88. Repurposing a barge as a floating pedestrian bridge, as shown in Figure 89, avoids the need for driving pilings into the river channel. Temporary pedestrian pontoon bridges such as that shown in Figure 90 are an expedient solution for long crossings over still or slowly moving water. Several companies offer prefabricated dock floats and floating boat docks that could be adapted for this application. There is also a prefabricated pedestrian pontoon bridge system developed by the Japan Ground Self-Defense Force (JGSDF) known as the JGSDF Light Footbridge, shown in Figure 91.

Figure 88. Temporary pedestrian bridge for river crossing.

Figure 89. Floating bridge for a temporary river crossing and its approach road.

Figure 90. Temporary pedestrian pontoon bridge.

Rikujojieitai Boueisho / Japan Ground Self-Defense Force

Figure 91. JGSDF Light Footbridge, a prefabricated pedestrian pontoon bridge.

Temporary Bridges for Motor Vehicles

Like their pedestrian counterparts, temporary bridges used for motor vehicle traffic include a wide variety of designs. Several of the most prevalent types are described below.

Short-Span Temporary Bridges. Wide steel beams are sometimes used for short spans that are low to the ground, as shown in Figure 92. Prestressed concrete panels have also been used in a similar manner.

Figure 92. Short-span steel beam bridge.

Skidder bridges, also referred to as logging mats, laminated timber bridges, or other terms, are portable short-span bridges that are often built up from large timbers, as shown in Figure 93. In a typical design, each panel is 4 ft wide and 20 ft long and is comprised of 6 in. by 10 in. or 6 in. by 12 in. timbers, which are held together laterally by large screws and threaded rods (Vermont Agency of Natural Resources 2017). In most cases, two or more panels are placed side by side to provide the driving surface.

Vermont Agency of Natural Resources

Figure 93. Timber skidder bridge in a forestry application.

Prefabricated steel skidder bridges, also called bridge mats or panel bridges, are commercially available in various lengths and load capacities. An example is shown in Figure 94. Often these temporary bridges have tapered, ramp-like ends to simplify the transition to the adjoining surface and can be stacked for transport, as shown in Figure 95. The addition of forklift pockets and lifting rings could make skidder bridges even more versatile.

North Carolina Division of Forest Resources

Figure 94. Steel skidder bridge being placed with a grapple.

North Carolina Division of Forest Resources

Figure 95. Steel skidder bridges can be stacked for delivery to the sites where they are needed.

The log stringer bridge, an example of which is shown in Figure 96, is a traditional design that uses two or more logs as longitudinal beams. In rapid response situations in wooded areas, they can potentially be built with materials available at the site. To improve structural performance, the logs can be placed side by side and connected with cables (Blinn et al. 1998). Often a deck of small logs or wood planks running laterally is nailed or screwed to the log beams. Diagonal braces can be added for stability, and a layer of soil, gravel, or wood chips can be added to smooth the driving surface. If such a bridge is constructed from sawn timbers, it is usually called a sawn timber stringer bridge or timber beam bridge.

Figure 96. Log stringer bridge.

Figure 97 shows the construction of a steel pipe bridge, which is conceptually similar to a log stringer bridge (personal communication with Jerry Downey, President, Savona Equipment, Ltd, 2021). The design uses large-diameter pipes welded side by side as beams and a gravel running surface installed over the pipes. Endplates tie the structure laterally and keep gravel out of the pipes. Longitudinal side plates or smaller pipes can be tack-welded on each side to retain the gravel. For lateral stability, cables or upper and lower tie bars connecting the pipes can be added every few feet, along with diagonal braces. Weep holes at the pipe bottoms limit moisture accumulation.

Figure 97. Steel pipe bridge under construction.

Bailey Bridge. Perhaps the most famous type of temporary bridge is the Bailey bridge, shown in Figure 98 to Figure 102. Developed for the British military in the early years of World War II, the design was soon adopted by other Allied forces and played a crucial role in numerous battles with its portability, rapid installation and removal, and ability to span up to 450 ft. The design has subsequently been used for many temporary civilian roadway and pedestrian bridges, such as the highway bridge shown in

Figure 98. It is also used for semipermanent and permanent installations, especially in hard-to-reach areas. The patents for the Bailey bridge expired in the 1970s, making it a nonproprietary design that is produced by numerous companies worldwide.

Figure 98. Bailey bridge used as a temporary highway bridge.

As shown in Figure 99, the Bailey bridge is a type of through truss comprised of interlocking 10 ft modules. Each component is small enough to be carried in most trucks and light enough to be carried by a few people. For example, the side panels are 5 ft high and 10 ft long and weigh less than 600 lb. This allows them to be lifted manually by groups of about six people without a crane. Lateral beams called transoms connect the trusses and support 10 ft steel stringers. Wood deck boards or other decking materials are placed across the stringers. Rollers in the supports allow the bridge to be launched incrementally from one side of a waterway or ravine, an essential feature for a military bridge. This design has also been adapted for use as a pontoon bridge, suspension bridge, and drawbridge (Russell and Thrall 2013).

Figure 99. Bailey bridge display, illustrating the side panels, transoms, stringers, decking, and roller footings, with a launching nose visible at the far left.

To support heavier loads or longer spans, the side trusses can be doubled vertically and doubled or tripled horizontally, as shown in Figure 100 and Figure 101. Alternatively, a pedestrian walkway can be attached on the outer side of the truss. At some sites, support towers have been assembled from side panel sections rotated to vertical orientation, as shown in Figure 102.

Figure 100. Bailey bridge with horizontally tripled and vertically doubled panels.

Figure 101. Bailey bridge with horizontally and vertically doubled side panels; semipermanent application.

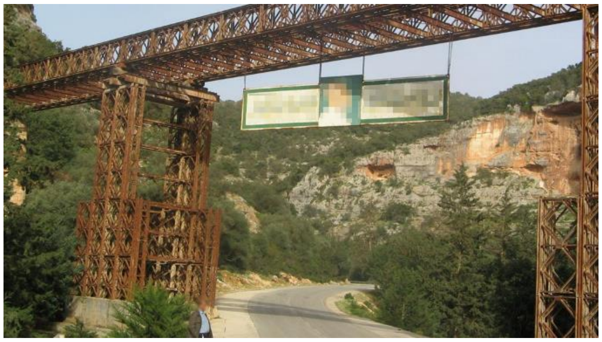


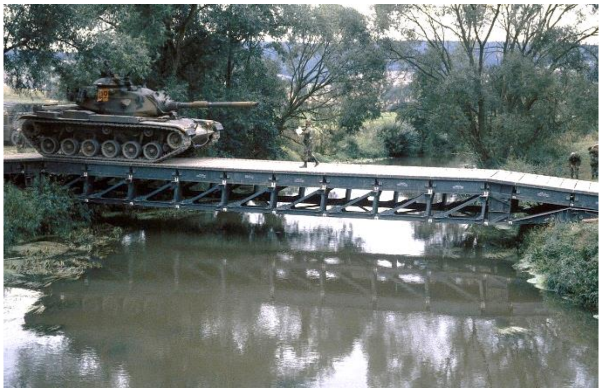
Figure 102. Bailey system side panels turned vertically and used as support towers.

Other Modular Panel Bridges. Various rapid-assembly panel bridges are in commercial production (Structure Design and Rehabilitation, Inc. 2005). Many are derived from the Bailey bridge design. For example, the Mabey-Johnson Logistic Support Bridge (often simply called a Mabey bridge) is used in both civilian and military applications. An example of a Mabey bridge under construction is shown in Figure 103. It looks similar to a Bailey bridge but has larger panels that are designed to support heavier loads. Transportation agencies in New York State, among other jurisdictions, have used them extensively in temporary applications (Mabey Bridge & Shore, Inc. 2008).

U.S. Army / Flickr

Figure 103. Assembling a Mabey bridge.

There are also several types of portable modular girder bridges. One example is the medium girder bridge (MGB), shown in Figure 104. The MGB is a military design that uses a high-strength zinc-magnesium-aluminum alloy to limit the weight of all components to 600 lb or less. The bridge is designed for rapid hand assembly. Like the Bailey bridge, it is supported by rollers that allow it to be launched from one side of a waterway or ravine.



Michael Haggerty / U.S. Navy

Figure 104. MGB.

Other Prefabricated Steel Truss and Girder Bridges. Introduced in 1935, the Callender-Hamilton bridge, shown in Figure 105, is a medium-span truss. It is built up from standardized truss bars that can be bolted to gusset plates by unskilled laborers, with no need for welding. The design has been used in both temporary and permanent applications. Due to the time required for bolt tightening, assembly is slower than the Bailey-type designs, which are held together by pins.

Figure 105. Callender-Hamilton bridge (permanent application).

Prefabricated modular steel beam bridges such as that shown in Figure 106 are available from various manufacturers. Some models incorporate prefabricated decks and side rails, as shown in Figure 107. Portable steel or aluminum tub girder designs could also be considered but do not appear to be in commercial production.

Figure 106. Prefabricated temporary bridge (viaduct application).

Vermont Agency of Natural Resources

Figure 107. Prefabricated temporary girder bridge.

Adaptive Reuse. Rapid response situations require ingenuity. For example, some practitioners have utilized salvaged steel beams to build temporary bridges, as shown in Figure 108. Railroad flatcars, gondola cars, and boxcars have also been repurposed as temporary bridges, as have flatbed semi-trailer frames (Blinn et al. 1998). A bridge constructed from a railroad flatcar is shown in Figure 109.

© Kai3952 / Wikimedia Commons / CC BY-SA 4.0

Figure 108. Temporary bridge under construction featuring salvaged steel beams.

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Figure 109. Railroad flatcar converted to a temporary bridge.

Flat racks (officially called "flat folding wall end containers") are a type of intermodal shipping container with fold-down ends or folding corner posts and are produced in 20 ft and 40 ft lengths. The ends or end-posts fold inward, allowing them to be stacked when not in use. With their substantial load capacity, they are useful as temporary girder bridges, as shown in Figure 110 (Parker 2019).

Chuck Henry Sales, Inc., used with permission

Figure 110. Flat racks (ISO folding end wall containers) have been used as bridges.

Scissor Bridges. Various types of scissor bridges have been designed for very rapid deployment in battlefield applications (Russell and Thrall 2013). Although these designs usually require a specialized launch vehicle such as that shown in Figure 111, the underlying principle of a hinged portable bridge is transferrable to civilian rapid response applications, for example, the roll-up wheelchair ramp shown in Figure 85.

Kevin Quihuis, Jr. / U.S. Marine Corps

Figure 111. M60A1 armored vehicle landing bridge.

Researchers in Japan developed a multi-section scissor bridge, shown in Figure 112, for rapid response to earthquakes and other disasters (Chikahiro et al. 2017). The bridge resembles a scissor lift turned on its side, with a horizontal pantograph that supports telescoping deck segments. The pantograph is launched by hydraulic actuators mounted on a mobile platform.

Hiroshima University / https://www.youtube.com/watch?v=9RL9IB90M20

Figure 112. Scissor-type mobile bridge.

Floating Bridges. Various types of floating bridges have long been used to cross calm or slow-moving water. For instance, barges are sometimes repurposed as temporary bridges; Figure 88 shows a barge that has been converted into a floating bridge serving pedestrians and light wheeled traffic.

Pontoon bridges can be used to cross wide expanses of calm or slowly moving water. In their simplest form, they are simply a set of boats or floats anchored side by side and connected by planks or gangways. This type of bridge has probably been used for more than 2,000 years and features prominently in the military histories of Ancient China, Ancient Greece, and Ancient Persia, among other civilizations. Major technical advances were made during the American Civil War (1861 to 1865), as demonstrated in Figure 113, and again in the World War II era (1939 to 1945). The design remains in military use, as shown in Figure 114.

Matthew Brady / U.S. National Archives

Figure 113. Civil War pontoon bridge across the James River in Virginia.

C.W. Griffin / U.S. Marine Corps

Figure 114. Type M4T6 prefabricated pontoon bridge.

The weight that can be supported by a pontoon bridge is mainly a function of the size and spacing of the pontoons. The military Lightweight Modular Causeway System, shown in Figure 115, combines inflatable pontoons with prefabricated deck panels that are usually installed with an all-terrain forklift. Pontoon bridges are also used in civilian applications. For example, Figure 116 illustrates a pontoon system that was used to detour highway traffic around a rockslide.

U.S. Army Corps of Engineers

Figure 115. The Lightweight Modular Causeway System is designed for heavy loads.

Figure 116. Pontoon bridge bypassing a rockslide.

In the 1980s, a rapidly deployable, modular, truck-transportable pontoon bridge was developed in the former Soviet Union. The United States copied and upgraded the design as the Improved Float Bridge (Ribbon), a triple-hinged pontoon with an integral deck (U.S. Army 1988). The design is shown in Figure 117 and Figure 118. Individual bays (segments) are offloaded from the delivery vehicle in folded position and unfold in the water. Motorized rafts are then used to position the bays for connection and anchorage.

Robert Farrell / U.S. Army (released)

Figure 117. Improved Float Bridge (Ribbon), a prefabricated pontoon bridge designed for military applications.

Sgt. Francis Horton / U.S. Army (released)

Figure 118. Deployment of an Improved Float Bridge (Ribbon).

Abutments for Temporary Bridges

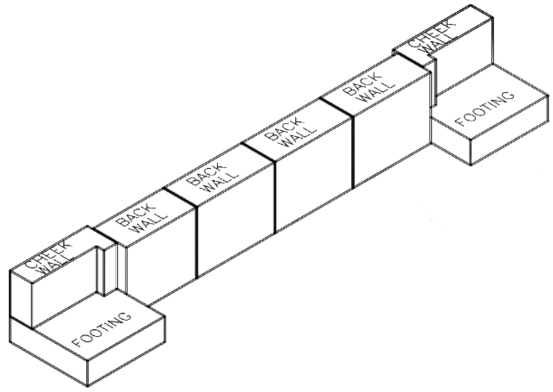
When the use of a temporary bridge is planned in advance, conventional bridge abutments such as steel or timber pilings, caissons, sheet pilings, concrete footings, or geotextile-reinforced soil (GRS) can be designed and installed. In some cases, a set of existing bridge abutments can be reused.

In rapid response situations, the time available for the design and construction of temporary bridge abutments or footings is limited. As illustrated in Figure 99, many of the military rapid bridging systems incorporate prefabricated spread footings that can be used on unimproved soil. Other methods that have been used to support expedient bridges include the following:

- Sill abutments
  - Timber sills, shown in Figure 119
  - Prefabricated concrete abutments, illustrated in Figure 120
  - Gabions (wire baskets filled with stones), shown in Figure 121
- Spread footings
  - Wooden pads or mats
  - Assemblies of heavy timbers or railroad ties
  - Concrete slabs on grade
  - Extension of the bridge superstructure over a large gravel pad or area of native soil to spread the abutment load
- Helical anchors (also called screw piles), shown in Figure 122

U.S. Department of Agriculture, Forest Service

Figure 119. Timber sill abutment.



Mabey Bridge & Shore, Inc. 2008

Figure 120. Precast temporary footing blocks used on county projects in New York State.

Chris Bielecki / U.S. Department of Agriculture, Forest Service

Figure 121. Preparation of gabion for use as a temporary bridge footing after a forest fire.

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Figure 122. Helical anchors (screw piles).

Removal of Temporary Fills, Bridges, and Culverts

Expedient fills, bridges, and culverts are often implemented using emergency authority that bypasses the normal requirements for public consultation and environmental review. As a result, it is important to ensure that their appearance, function, and management do not convey a false sense of permanence.

When the facility is no longer needed, it should be promptly removed, and the site should be restored to substantially its original condition. To assist with this process, the predeployment conditions should be documented with photographs or videos. Good documentation and attention to detail during removal and restoration can help avoid disputes with landowners and resource agencies.

Chapter 6. Temporary Roundabouts

Introduction

Adverse events often result in traffic signal outages due to the loss of electrical power or damage to the signals themselves. At major intersections especially, the resulting queues, delays, and crashes can interfere with incident response, evacuation, or the rerouting of traffic to bypass the affected area. A promising expedient solution that emerged from the damage inflicted by Hurricane Florence in 2018 is the temporary roundabout.

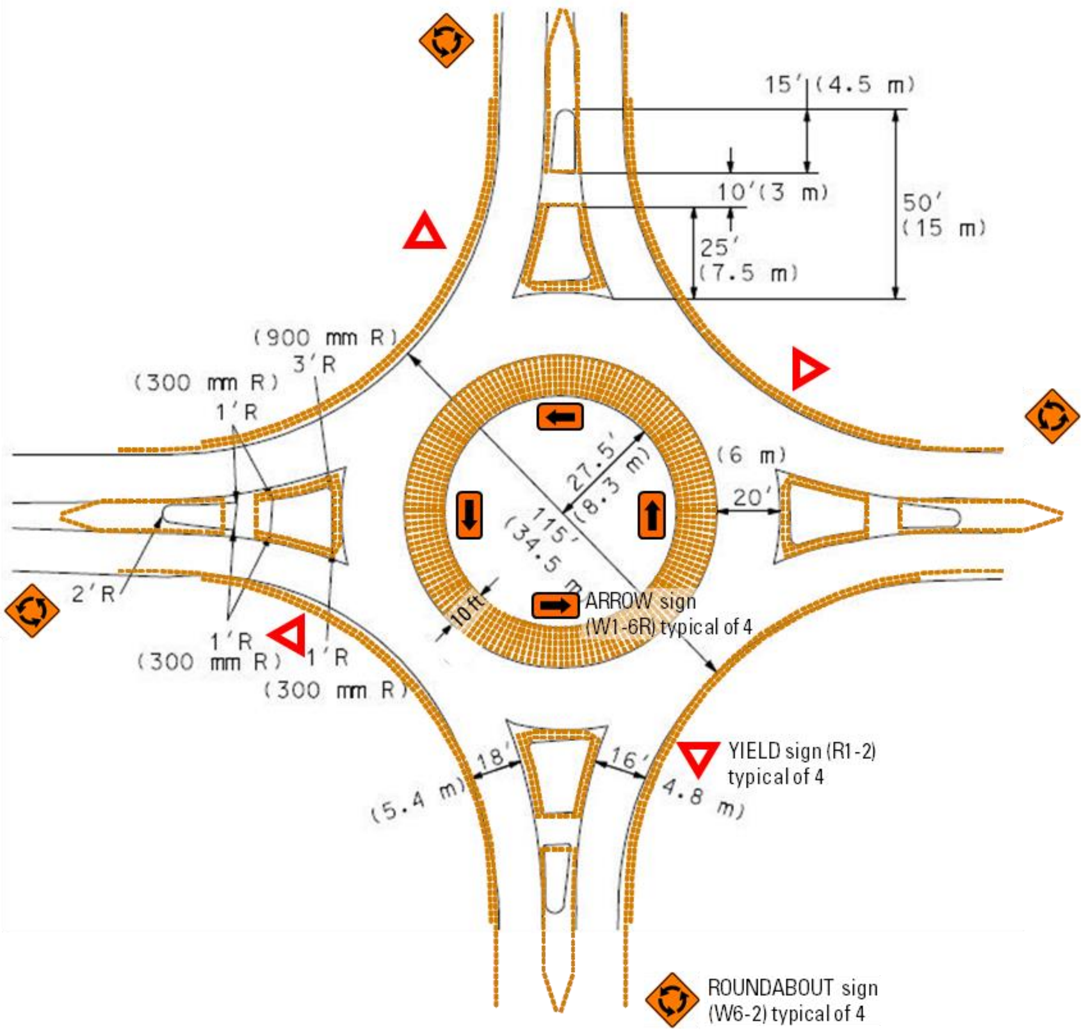
In 2018, Hurricane Florence battered the coastal Carolinas with torrential rain, a 10 ft storm surge, and 100 mph winds (Schroeder 2020). Many residents of Wilmington, North Carolina, sheltered in place, but flooding cut off the city from the rest of the mainland. Electric power was lost, and traffic signals went dark. Smaller intersections operated satisfactorily as all-way stops, but traffic operations at major intersections were problematic due to crashes and severe backups. This unfortunate combination of events led to the development of temporary roundabouts, an example of which is shown in Figure 123.

Wrightsville Beach Fire & Rescue

Figure 123. Temporary roundabout in Wilmington, North Carolina (2018).

Implementation

In Wilmington, the temporary roundabouts were implemented using traffic cones, but there was a tendency for the cones to be knocked down by traffic. Drums or vertical panels could also be used. Another possibility is to define the roundabout using sandbags, which are less easily disturbed by traffic. A design for a temporary sandbag roundabout is shown in Figure 124. To help prevent the sandbags from "migrating," two or more rows can be used in areas where overtracking is likely.



Source: FHWA

Figure 124. Typical dimensions for a single-lane temporary roundabout using sandbags, with comparison to a typical permanent roundabout.

All of the temporary roundabouts implemented in Wilmington were single-lane designs. Although double-lane temporary roundabouts may be possible in some locations, the available space is often limited by existing curbs or pavement. Single-lane designs are more likely to fit within these space constraints and usually provide much more traffic capacity than an all-way stop.

Design

The fundamental principles for temporary roundabouts are the same as those for permanent roundabouts, with entering traffic yielding to vehicles that are already circulating. Traffic flow is counterclockwise around the central island, which is usually circular or slightly oval.

As with any roundabout, traffic should pass through a series of reverse curves that are laid out so as to prevent vehicles from exceeding about 20 mph, which corresponds to a curve radius of approximately 100 ft along the fastest possible path through the roundabout (NACTO 2013). A vehicle entering the roundabout will steer to the right as it passes the splitter island area, steer to the left to go around the central island, and steer to the right to exit. Figure 125 illustrates the fastest path (also called the racing line) at an actual car racing track. As shown in the photo, the drivers do not stick to the centerline but use the entire width of the road space to expand their radius of curvature. The radius of the fastest path is measured along this wider expanse.

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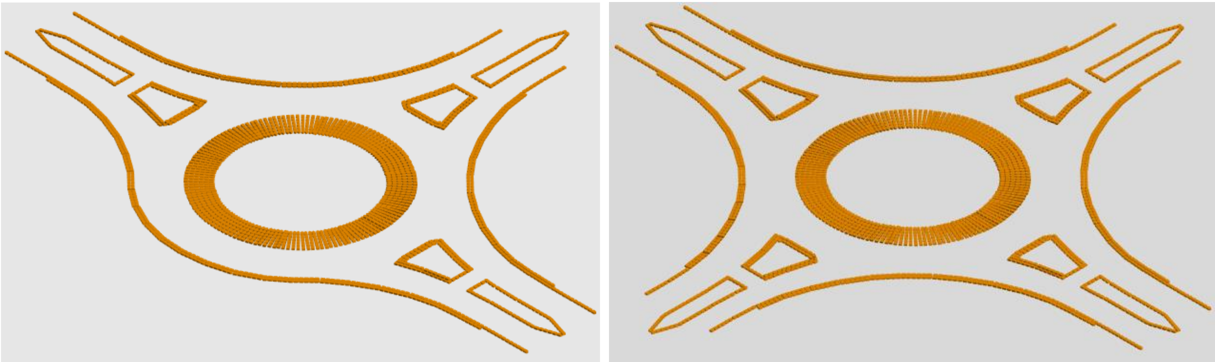
Figure 125. Racing line illustrating the fastest path through a racetrack.

Verifying the fastest path is particularly important for three-leg roundabouts, where a common pitfall is a too-flat radius on one of the approaches. In general, the geometric design of a three-leg temporary roundabout should be similar to the layout for a four-leg roundabout, except that one splitter island is eliminated and the circulatory roadway on that side becomes a simple arc. The geometries of three-leg and four-leg sandbag roundabouts are illustrated in Figure 126.

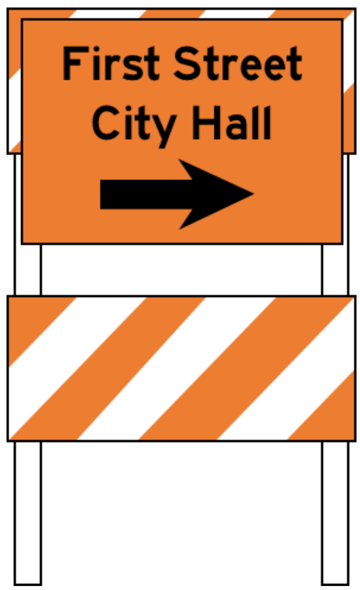


Source: FHWA

Figure 126. Three-dimensional renderings of three-leg (left) and four-leg (right) sandbag roundabouts.

Permanent roundabouts are usually designed to accommodate large trucks (often the AASHTO WB-65 design vehicle) making left turns. Due to space limitations within the existing curbs or pavement, accommodating these vehicles may not be possible when converting an existing signalized intersection to a roundabout. Nevertheless, it is usually possible to accommodate trucks that are going straight through the temporary roundabout. In many cases, an alternate route can be devised to eliminate the need for large trucks to turn left at the temporary roundabout. It might also be possible to accommodate a limited number of long trucks by making arrangements to move cones/drums/vertical panels temporarily or allowing trucks to drive over the sandbags.

Roundabout signs (W6-2) should be placed at each approach. Yield signs (R1-2) must be placed at each entrance to remind drivers to yield to circulating traffic. Arrow signs (W1-6R) pointing to the right, or similar signage such as chevrons pointing to the right, should be placed on the central island at each approach; these signs remind entering drivers that the traffic on the circulatory roadway is one way and proceeds counterclockwise. Street name, route marker, or destination signs can be placed near the middle of each inner splitter island to identify each exit; these signs can be mounted low (e.g., on a Type I barricade, as shown in Figure 127), and the horizontal angle of the signs can be adjusted to optimize visibility from approaching vehicles. If available, temporary pavement marking tabs can be used to enhance nighttime delineation of the temporary roundabout.



Source: FHWA

Figure 127. Wayfinding signs facing exiting traffic can be placed on a Type I barricade inside each splitter island.

Any existing signs that conflict with the roundabout signage or cause confusion should be covered or removed. The electrical power for the traffic signal system should be switched off until the temporary roundabout has been removed, especially if there is a possibility that power will be restored without advance notice.

In general, the field layout of temporary roundabouts can be accomplished using simple tools such as rope, spray paint, and a measuring tape. Providing a complete set of paint marks for the initial installation will make it easier to reset any temporary traffic control devices or sandbags that are moved out of position by traffic. Usually, the process begins by locating and marking the center point of the roundabout. One person then holds the rope at the center, and another measures the radius of each curve and marks the pavement accordingly. If desired, the boundaries of the roundabout can be tessellated (converted to multi-sided polygons) to simplify setup. This simply involves marking several radius points on the pavement as dots and then using rope or a board as a template to connect the dots with straight-line paint marks.

More details about the geometric design and signage for roundabouts can be found on the Federal Highway Administration (FHWA) and National Cooperative Research Program (NCHRP) websites and in state highway department design manuals.

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