

Use of GPR in 2D and 3D Imaging of Bridge Footings and Scour Studies

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ABSTRACT

GPR was used at two different Massachusetts bridges to help assess the stability of their foundations. At one highway bridge, GPR was used to confirm the lateral extent of a bridge footing, while at another it was used to help evaluate the extent of river scouring at the bridge's piers.

During the bridge footing study, data were collected continuously along a 2-foot survey grid using a GSSI SIR System-2 and monostatic 900, 400, and 200 MHz antennas. CMP gather measurements were made using bistatic 400 MHz antennas with the intent of producing CMP stacked sections of each survey line in the grid and imaging the footing using tomography.

Because of its unexpected shallow depth, the 900 MHz antenna provided the best 2D resolution of the bridge footing's transverse and longitudinal sections. 3D data imaging from the data collected continuously failed to produce a clear image of the bridge footing, although this is partially attributed to a heterogeneous mixture of metal scraps, boulders, and cobbles in the topsoil covering the bridge footing. The CMP gathers helped establish the interval velocity through the topsoil, and hence give accurate depths to the footing. However, because CMP gather measurements were very time-consuming using only two antennas and 3 cm offsets, we were unable to collect a sufficient number of CMP gathers to produce a meaningful CMP stacked section. Imaging the bridge footing using radar tomography in the future may provide the highest resolution 3D data, but is currently impractical and costly using a two-antenna array.

A monostatic 200 MHz antenna was used to map sediments up to 3 feet below the Charles River water-bottom. Data were collected continuously between, and upstream from, existing bridge piers along survey lines spaced approximately 10-feet apart. The water velocity, and hence the depth to the river-bottom, was derived from existing Cole-Cole Distribution Models (Cole and Cole, 1941) assuming a resistivity of 1,000 ohm-meters and a temperature of 55 F. Because of the strong water-bottom reflector and an adequate line spacing, 3D images derived from compiling 2D data were adequate in defining at least one potential area of scour immediately upstream from a bridge pier. Due to a lack of velocity information below the water-bottom, however, other areas which had been potentially scoured and replaced with fine river-bottom sediments may not have been identified. The application of radar tomography, with use of a multi-antenna array, could enable the determination of river sediments velocities, and help more reliably identify those areas which have been scoured and subsequently filled in by fine river sediments.

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INTRODUCTION

As part of a larger bridge stability study for the Federal Highway Administration, ground penetrating radar (GPR) was used to image the lateral extent of, and depth to, a bridge footing at one eastern Massachusetts bridge. GPR was also used to help locate areas of river-bottom scouring (i.e. removal of fill material used to support the bridge footings and abutments) at another eastern Massachusetts bridge. In both instances, data were evaluated using conventional 2D processing/interpretation techniques. Data were collected in the field using monostatic and bistatic radar antennas with the intent of producing high-resolution 3D images of the bridge footings. One objective was to determine whether the additional information yielded by such detailed acquisition and processing justified the extra field time and cost.

BRIDGE FOOTING STUDY

The goal of the Federal Highway Administration study was to provide a high-resolution image of the bridge footing using a non-invasive, non-destructive technique. The lateral dimensions of the bridge footing provided by such a survey, would then be used to help assess the loading capacity of the bridge. As fill materials used in construction typically contain little or no clay, we felt that use of ground-penetrating radar would provide a high-resolution image with minimal field effort and cost. We used A GSSI SIR System-2 digital radar system to collect data in both continuous and “point” (i.e. stacking) modes, with ground-coupled antennas ranging in frequency from 200 MHz to 900 MHz.

The depth to top of the bridge footing (i.e. the amount of fill overlying the footing) was unknown, although it was likely to be located within a few feet from ground surface. As-built specifications, indicated that the bridge footing was approximately 36 by 6 feet (11 by 1.8 meters). A survey grid, having nodes at every 2 feet (0.61 meters), was established and data were collected continuously along survey lines oriented both parallel and perpendicular to the bridge footing. Data were collected along lines spaced 1 foot apart parallel to the bridge footing, while a spacing of 2 feet was used to collect data along transverse survey lines. Initially, a monostatic 400 MHz antenna was used to collect data within a 40 nanosecond (ns) range. However, when the reflector corresponding to the bridge footing appeared on the records at a two-way travel time of about 10 ns, a 900 MHz antenna was then used to record data continuously along survey lines. Some data were also collected using a 200 MHz antenna to determine the depth to the bottom of the bridge footing; this data did not provide any useful information. We also conducted 17 common-midpoint measurements (CMPs) using bistatic 400 MHz antennas along Line 0+10S to determine the interval velocity of the fill, and hence the depth to the bridge footing.

Figure 1, showing data acquired continuously along Line 0+03W parallel to the centerline of the long axis of the bridge footing but 3 feet west of it, is a 2D image of the bridge footing as it appears from ground surface. The northern and southern extent of the bridge footing appears at 0+06N and 0+34S, respectively, having a total length of 40 feet (12.2 meters). Because of diffraction at the edges of the bridge footing, there may be up to a 1 foot (0.3 meter) error.

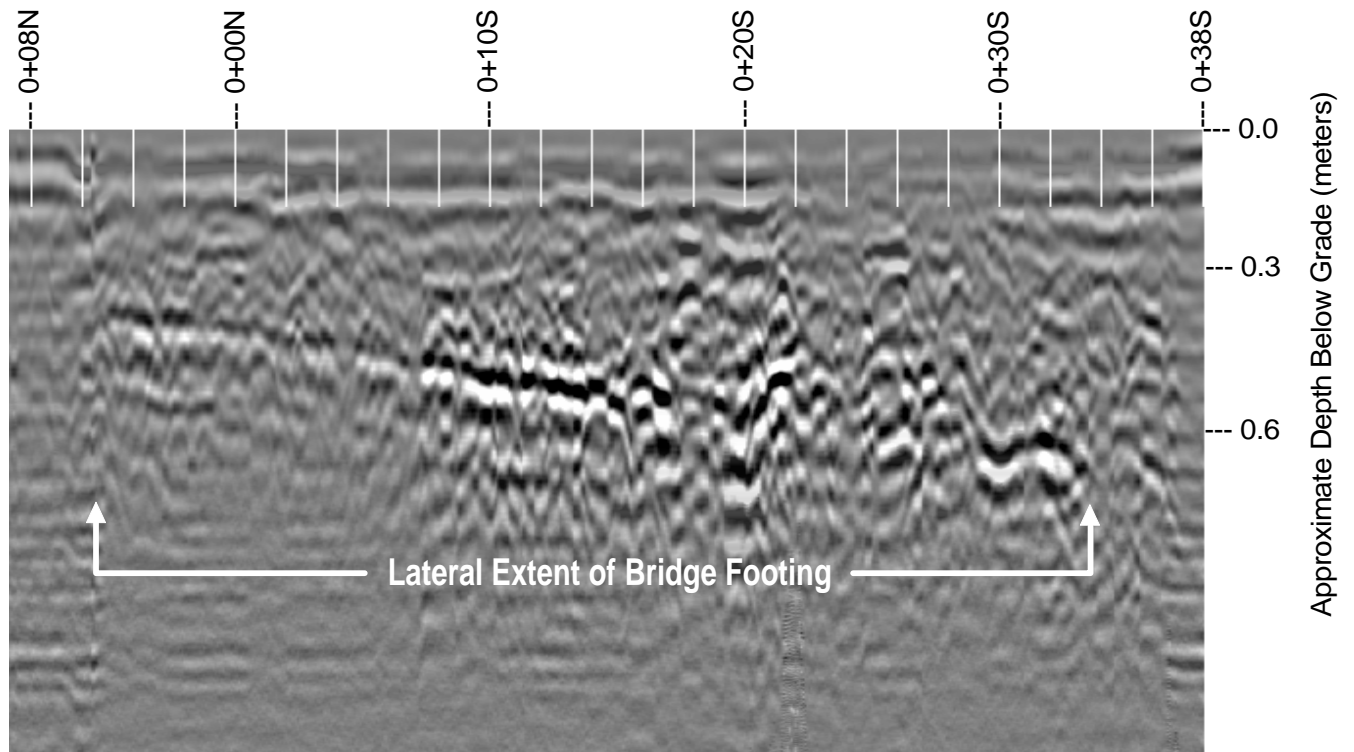


Figure 1: An example 2D profile along Line 0+3W. The footing appears deeper at Station 0+34S, as the amount of fill material increases to the south. Also, the reflector is irregular between Stations 0+20S and 0+30S because cobbles and rubble within the overburden produce hyperbolic reflections which interfere with it. These heterogeneities within the fill also scatter GPR signal away from the bridge footing so reflections from the footing itself are weak.

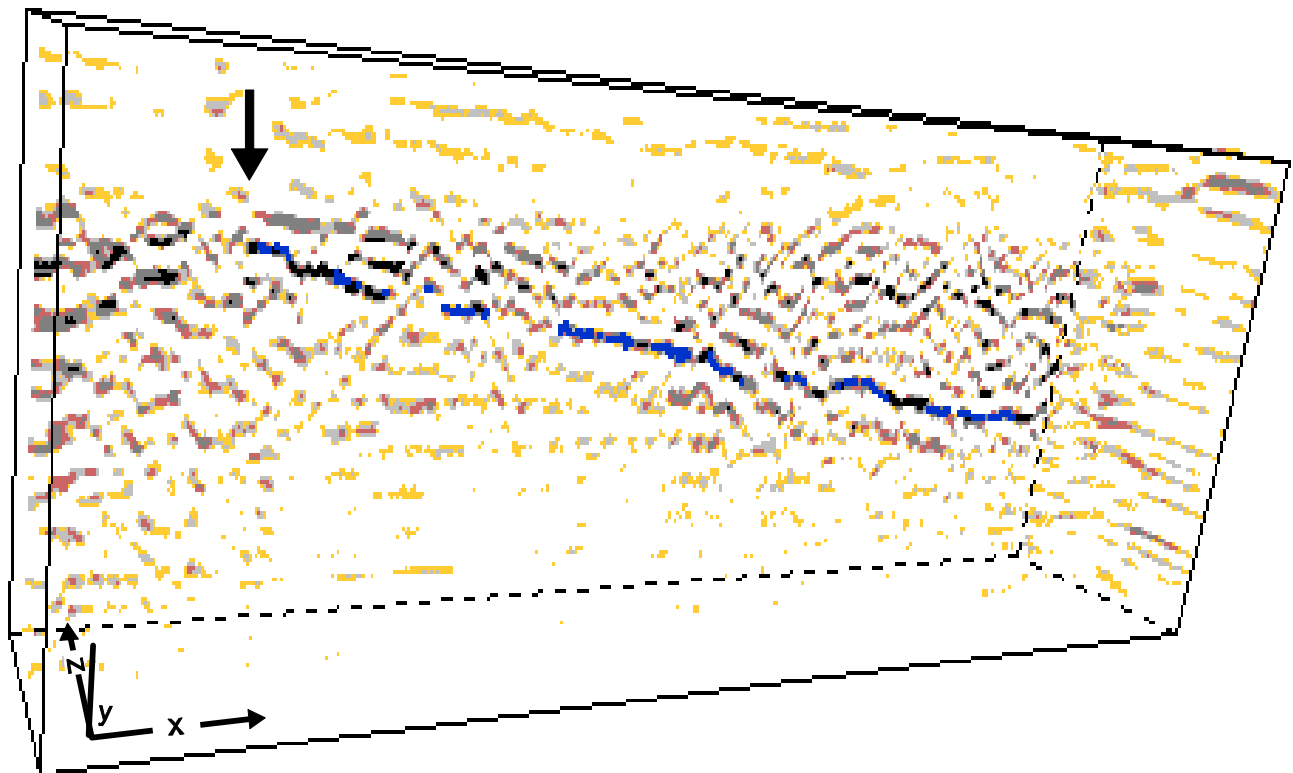


Figure 2: 3D image generated using GSSI's 16-bit version of Radan for Windows 3D module. Image was generated by data from 12 survey lines, spaced 1-foot (0.3 meters) apart, and each line being 678 scans long (x-dimension), with each scan having 1024 samples/scan. The approximate northern extent of the bridge footing is denoted by the arrow. Data were not migrated prior to producing the 3D image.

(Migration was not done on these data.) The bridge footing, which is assumed to be constructed at horizontal, appears deeper on the radar record towards the south. This is attributed to the surface elevation and amount of fill material increasing to the south. Also note that between Stations 0+20S and 0+30S, the reflector corresponding to the bridge footing is irregular, and is attributed to cobbles and rubble within the overlying fill material. These heterogeneities within the fill material produce small hyperbolic reflections immediately above the footing reflector, which constructively interfere with it; they also scatter GPR signal away from the bridge footing so reflections from the footing itself are weaker.

Two-dimensional images were then assembled into 3D GSSI-formatted *.dzt and ASCII files to determine whether the images generated by several different 3D imaging software packages provided additional information. First we generated a 3D image using GSSI's 16-bit version of RADAN for Windows, 3D Module. Data from Lines 0+06W through 0+06E were assembled into twelve files. Each file was 678 scans long, with each scan having 1024 samples per scan. Lines were evenly spaced 1 foot (0.3 meters) apart, with no data at the centerline (0+00E) of the bridge footing due to physical interference from the bridge's support columns. Figure 2 shows the resulting 3D image, which took over 10 hours to generate due to intricate data manipulations. The image of the bridge footing is difficult to distinguish, partially because of the display limitations inherent with 16-bit data. Also, the program's ability to "interpolate" in-between survey lines seems somewhat limited, especially if there is an insufficient density of survey lines.

Figure 3 is a 2D image generated from contoured ASCII data of the same twelve data files. The image shows the depth to the top surface of the bridge footing. First, data were displayed as profiles and the two-way travel times to the bridge footing reflector "picked" using one of several commercially-available automatic picking programs. Two-way travel times were then converted to depths using the velocity assumed from the CMP measurements. Three-column (x,y,z) ASCII data files were output for each profile and then concatenated into one large data file and contoured using a commercially-available software package.

The "picking" and storing the data in an ASCII format provided an accurate and rapid way of recording the depth to the bridge footing where it was readily apparent from the radar record. However, where there were irregularities in the bridge footing reflector, the automatic picking program occasionally misinterpreted the location of the bridge footing. Fixing our interpretation was somewhat time-consuming, as each file had to be re-opened and manually re-picked at each mistracking. Ultimately, Figure 3 required almost as much time (about 8 hours) as Figure 2 to generate.

Contouring appears to be a better way to interpolate data in-between survey lines without having to spend an inordinate amount of field time collecting a high density of lines. Contouring, however, did generate some artifacts in the data, however, which are evident at the edges of the bridge footing. Note that the north edge of the bridge footing appears irregular. This is partially attributed to diffraction of GPR signal at the edges of the concrete structure, which can be remedied by first migrating the 2D profile. However, these irregularities are also attributed to imperfections in the contouring method, part of which may be due to operator inexperience.

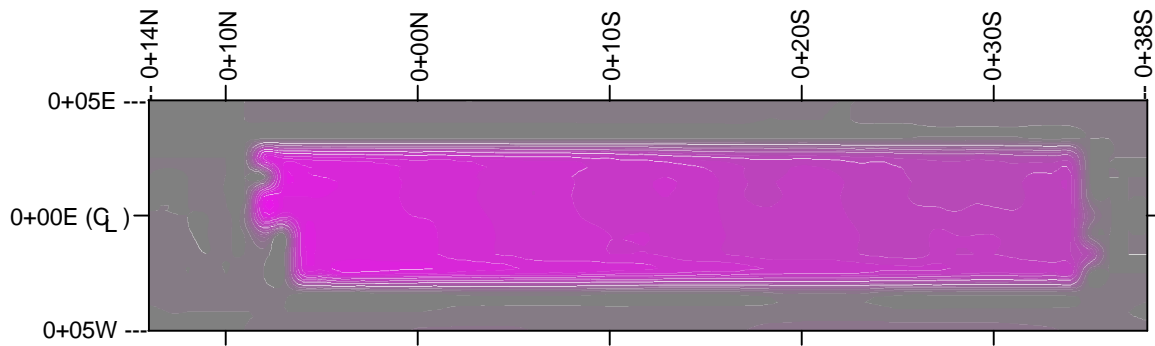


Figure 3: Two-dimensional contoured image of the bridge footing. This image was generated by first "picking" the two-way travel time to the reflector corresponding to the top of the bridge footing for each profile, then converting two-way travel times to depths using velocity information derived from several CMP measurements. Calculated depths were then contoured using a commercial software package. Note that the north and south edges of the bridge footing appear irregular. This is partially attributed to diffraction of GPR signal at the edges of the concrete structure (the data were not migrated), but also to imperfections in the contouring method. This image took approximately 8 hours to generate.

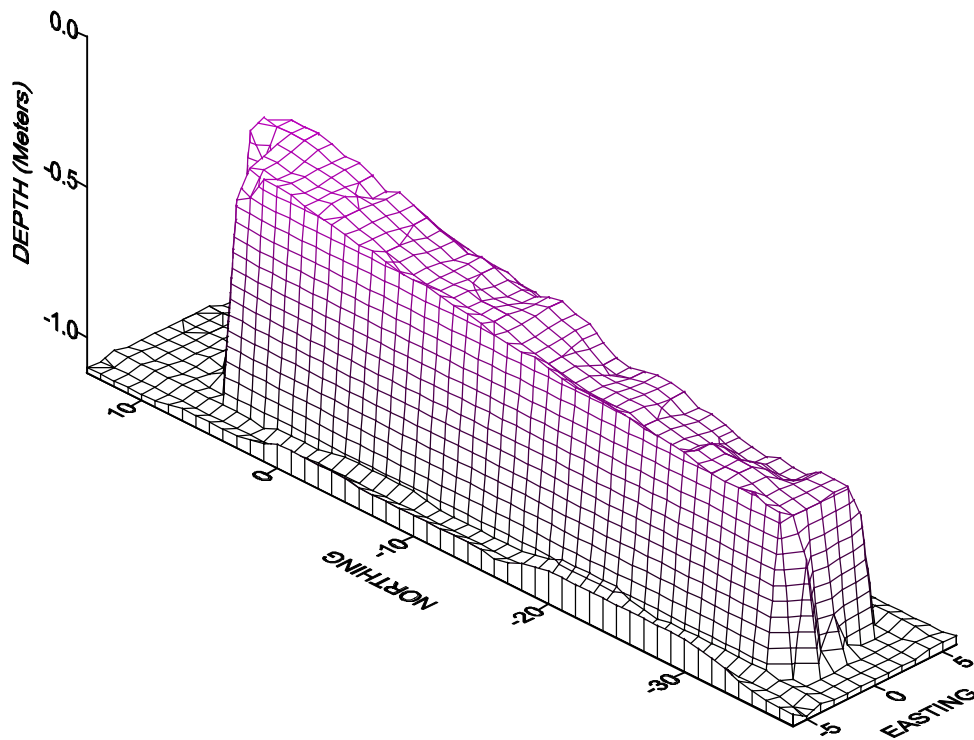


Figure 4: 3D image of bridge footing as displayed as depth from ground surface. This image took less than 0.5 hours to generate once data were prepared and contoured as they were in Figure 3.

Figure 4 is a 3D image generated by the same software package of the contoured data. The irregularities at the edges of the bridge footing appear less noticeable using this presentation, which took only an additional 0.5 hours to generate once data were prepared and contoured as they were in Figure 3.

During our bridge footing study we also attempted to generate 2D CMP-stacked images from our CMP measurements. Initially, it was our goal to acquire CMP data along several lines near the northern edge of the bridge footing and attempt to generate a 3D image from radar tomography. However, after taking four hours to complete seventeen measurements, it became apparent that such a survey would be prohibitively time-consuming and expensive, so CMP measurements were only acquired along Line 0+10S, transverse to the bridge footing. In all, seventeen (17) CMP measurements were made at 1-foot (0.3 meter) station spacings, using 3 cm offsets. CMP measurements determined that the fill's velocity varies between 0.2694 - 0.301 ft/ns (8.21 -9.144 cm/ns), with the best correlation at a value of 0.299 ft/ns (9.13 cm/ns). This value was used to determine the approximate depth to the bridge footing in the procedures above. CMP measurements were converted to SEG-Y format and stacked. Compilation of a CMP section did not produce meaningful results, in part due to an inadequate number of CMP measurements along the length of Line 0+10S, but also due to using too low an antenna frequency (400 MHz) for the measurements.

BRIDGE SCOUR STUDY

In recent history, several bridges have failed due to river-bottom scour undermining the bridge's supporting structure. Of note, was the failure of one New York State Thruway bridge over the Schoharie Creek, south of Albany. Several Massachusetts Turnpike Authority and Highway Department bridges span the Charles River in eastern Massachusetts. Although much attention has been given to the deterioration of bridge decks and abutments, little has been done to study the effects of scour on these bridges.

In October, 1996, a large rainstorm produced over 8-inches of rainfall in the Boston, Massachusetts area, resulting in significant erosion of the Charles River embankment from flooding. We used our portable GSSI Sir-2 System to locate possible scour areas at one bridge along the Charles River. A 200 MHz monostatic antenna to continuously collect data upstream and downstream of, and in-between existing columns and footings. However, given the logistical limitations of performing a survey on moving water, we were unable to conduct CMP and other measurements using bistatic and/or multiple antennas.

Figure 5 shows one continuous profile located 5 feet (1.67 meters) south and upstream of the bridge. The high-amplitude reflection appearing at about an 8 foot (2.5 meter) depth corresponds to water-bottom. Weak, dipping reflectors at and immediately below the water-bottom reflector indicate a possible scour area near the east column which may have been subsequently back-filled with soft-river bottom sediments. Because the scour survey was conducted using a monostatic antenna and not bistatic or multi-channel antennas, we were unable to conduct CMP measurements and derive the velocities of the river-bottom sediments. Without the benefit of

West Column

LINE 0+05S

East Column
-- 0

-- 1

-- 2

-- 3

APPROXIMATE DEPTH (Meters)

Figure 5: River bottom profile, 2 meters upstream from bridge showing a possible scoured area near the east column that may have been subsequently back-filled with soft river-bottom sediments. For logistical reasons, data were acquired using a monostatic 200 MHz antenna. The lack of CMP and other multi-channel measurements rule out the possibility of using radar tomography to image the velocity contrast between hard-packed fill and water-bottom and the soft, river-bottom sediments that have filled in a previously scoured area.

CMP (and possibly radar tomography) derived velocities to help locate possible velocity contrasts between the hard-packed fill and water bottom and the soft, backfilled sediments, we were unable to verify whether this area had been previously scoured. Other potential areas, which were scoured and subsequently backfilled by soft river-bottom sediments, may not have been correctly identified, as they may not have been apparent in the reflection amplitude display of the continuous profiles.

Figures 6 and 7 show 2D contoured and 3D images of the water-bottom. Continuous profiles were assembled into 2D and 3D images using the same procedures to generate Figures 3 and 4. To determine the depth to the river bottom we used a velocity derived from existing Cole-Cole Distribution models (Cole and Cole, 1941), assuming a temperature of 55° F and a resistivity of 1000 ohm-meters. Because the water-bottom reflector had a high amplitude relative to other reflectors, the automatic picking program did an exceptionally good job locating the water-bottom reflector, saving significant time and expense in data reduction.

CONCLUSIONS

Three dimensional images can be readily generated from continuous profiles and sometimes provide additional information that would otherwise be difficult to see on a single GPR record. These 3D images can be generated several different ways, as demonstrated by this paper. Use of GSSI's 16-bit 3D imaging program was time-consuming, both in terms of acquiring field data at a high resolution line spacing and preparation of 2D data for 3D imaging, and did not readily produce a meaningful image. Use of a commercially available software contour package enabled interpolation and presentation of data in-between survey lines. This method is not as time-consuming, especially with the benefit of an auto-pick program. Both of these imaging techniques rely on the quality and presentation of reflection amplitude data and the subjective interpretation of the geophysicist(s).

Observing velocity changes in fill and water-bottom sediments is potentially more beneficial than imaging the amplitude of reflections. Direct measure of velocity would enable detection of scour that has been subsequently back-filled with soft sediments. Also, the influence of surface and near-surface anomalies is likely greater with a moving, ground coupled antenna. In our study, CMP measurements provided useful velocity information in determining the depth to the bridge footing. However, CMP measurements were very time consuming with the hardware limitations of current, commercially available, radar systems. Use of a 4-channel radar system would have cut the CMP acquisition time in half, but still would have been too labor-intensive and expensive to implement a radar tomography survey, which would have required CMP data to be collected along a high-density of parallel lines. There is a need for a multi-channel, inexpensive radar system allowing for multiple offsets and antenna frequencies.

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