Measuring Shear Wave Velocity Using MASW Method to Reduce Cost and Time required in Construction Projects

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Abstract: ***Surface wave method was introduced as a tool to the geotechnical and infrastructure engineering fields in the early 1980's. The non-invasive seismic method of multi-channel analysis of surface waves (MASW) is often used to map shear wave velocity variation of soil with depth. In an attempt to increase confidence in the interpreted shear wave velocity (Vs) profile as a result of the ambiguity in the analyzed dispersion characteristics, multichannel method is used in this research to characterize a test site on the ground of Veermata Jijabai Technological Institute (VJTI), Matunga, Mumbai. The multichannel analysis of surface waves (MASW) method originated from the traditional seismic exploration approach that employs multiple (twelve or more) receivers placed along a linear survey line. The present paper indicates results from MASW survey at a site along the VJTI college ground, for which the MASW data acquisition involved the use of a 12-channel PASI seismograph and a 12 nos. of 4.5 Hz Vertical geophones spaced at 5 m each and source offset 7m. The seismic source was a Sledge hammer (10 lbs). WinMasw 6.0 standard version software package was used to process and invert the Surface-wave seismic data in addition to generating the one-dimensional depth versus Shear Wave Velocity (Vs) profiles. The average shear wave velocity of the current study area is 228 m/s. The average shear wave velocity for Mumbai city is ranging from 110 to 350 m/s. The results determine benefits of using non-invasive MASW method in construction projects in a cost effective and time efficient manner as compared to Conventional Geotechnical method.***

Keywords: Construction projects, Multichannel analysis of surface waves, Non-invasive, Shear wave velocity, Surface wave method

1. Introduction

Multichannel analysis of surface waves (MASW) [8], [9] has emerged as a valuable technique for non-invasive seismic testing to evaluate shear-wave velocity (a proxy for shear stiffness) of the soil above bedrock during geotechnical site characterization [5], [8]. MASW first measures seismic surface waves generated from various types of seismic sources such as sledge hammer, analyzes the propagation velocities of those surface waves, and then finally deduces shear-wave velocity (Vs) variations below the surveyed area that is most responsible for the analyzed propagation of velocity pattern of surface waves. It analyzes dispersion properties of seismic surface waves (fundamental-mode Rayleigh waves) propagating horizontally along the surface of measurement directly from impact point to receivers. Shear wave velocity (Vs) is typically represented in 1-D (Vs versus depth) or 2-D (the variation of Vs along a depth profile) format. Shear-wave velocity (Vs) is one of the elastic constants and closely related to Young‘s modulus. Under most circumstances, (Vs) is a direct indicator of the ground strength (stiffness) and therefore commonly used to derive load-bearing capacity. In comparison to a conventional drilling approach, it is fully implemented on the ground surface (non-invasive), covers the subsurface continuously and provides more complete coverage.

2. Multichannel Analysis of Surface Waves-Study

2.1 Test Site

The test site Veermata Jijabai technological institute- open ground lies in $19^0 1'17.00''$ N latitude and $72^0 51'20.62''$ E longitude. (Figure 1)
Site dimension- Length – 75 m, Width – 20 m.
Total area – 1500 sq.m.
MASW survey is done along the open ground of the Institute, for which active type of survey is adopted using a seismic source sledge hammer to generate surface waves as the test site is free from natural activities such as traffic, thunder, tidal motion, atmospheric pressure change etc. which is a passive type of survey.

2.2 General procedure with MASW survey

A multiple number of receivers (usually 12 or more) are deployed with even spacing along a linear survey line with receivers connected to a multichannel seismograph (Figure 2). Each channel is dedicated to recording vibrations from one receiver.

The common procedure for a MASW survey usually consists of three steps- Data Acquisition: acquiring multichannel field records (commonly called shot gathers in conventional seismic exploration), Dispersion Analysis: extracting dispersion curves (one from each record), Inversion: back-calculating shear-wave velocity (Vs) variation with depth (called 1-D Vs profile) that gives

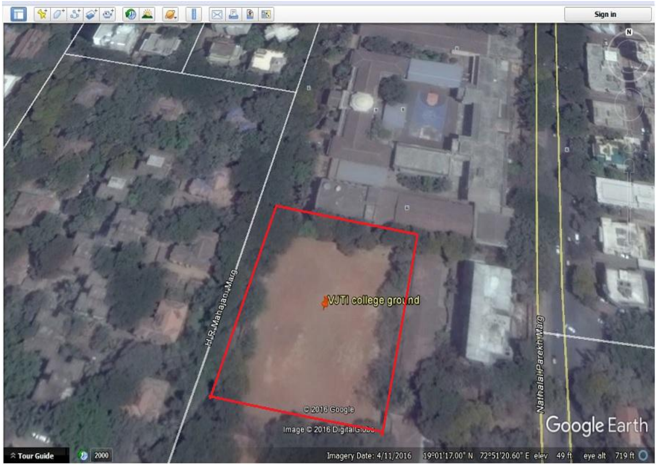

Figure 1: Test site location

theoretical dispersion curves closest to the extracted curves (one 1-D Vs profile from each curve). The field procedures for passive MASW and active MASW are different. The active survey is the most common type of MASW survey that can produce a 1-D vs. profile.

Surface waves are best generated over a flat ground within at least one receiver-spread length (D).

2.3 NEHRP site classification

The shear waves are travel near the ground surface therefore the shear wave velocity profile of soil column is used for Dynamic properties of soil which is important parameter for seismic site characterization and determination of shear modulus as well as site classification adhering to National Earthquake Hazard Reduction Programme (NEHRP) shown in Table 1 below

Table 1: NEHRP site class [1]

Class	*Average shear wave Velocity (Vs,30) variation (m/sec)*	*Description*
A	Vs30 > 1500	Hard Rock
B	760 - 1500	Rock
C	360 - 760	Very Dense Soil
D	180 - 360	Stiff Soil
E	< 180	Soft Soil

According to National earthquake hazard reduction programme (NEHRP), shear wave velocity variation with the subsurface soil type has been classified into classes A, B, C, D & E.

3. Field Methodology

The MASW Surface Wave method involved the use of a 12-channel PASI seismograph and twelve (12) 4.5-Hz vertical-displacement geophones spaced at 5 m intervals, as shown in Figure 3. A laptop was used to control the seismograph and data acquisition. The seismic source was a sledge hammer weighing 10 lbs, positioned at a 7 m offset from Geophone 12. WinMasw 6.0 standard software package (developed by the Eliosoft geophysical software and services) was used to process and invert the Surface-wave seismic data in addition to generating the one-dimensional depth versus Shear Wave Velocity (Vs) profiles. The MASW data was acquired at a rate of approximately 50 m/hr.

4. Data Acquisition and Processing

The multi-channel analysis of surface waves method (MASW) is a non-destructive seismic method employed to evaluate the stiffness of subsurface materials. It analyzes dispersion properties of seismic surface waves (fundamental-mode Rayleigh waves) propagating horizontally along the surface of measurement directly from the point of impact (source-sledge hammer) to the receivers (geophones). For each dataset, a dispersion curve representing the fundamental Rayleigh wave is picked. The curve is inverted to obtain a one-dimensional Vs model versus depth.

The acquired data were processed using WinMasw 6.0 standard software. This software is used to process and invert surface wave data, and produce one-dimensional shear wave velocity, Vs, profile. The vertical profile is obtained by the inversion process of the formerly picked dispersion curve which is the last step. Inversion is made by means of an optimization process (genetic algorithms) that requires the computer a big calculation effort. The result is though more reliable and can give an estimation of the outcome reliability too (standard deviations). In the beginning, when dataset is uploaded before doing the dispersion analysis the dataset should be filtered. The main purpose for using filters is to eliminate disturbances which could alter the acquisition itself. Such disturbances are found in the instrument's usage environment and are generally picked up by the cables lying on the terrain and by the geophones. So, the dataset is filtered under low pass filtering tab (to eliminate high frequencies) setting limits of frequency 0-50 Hz, which provide clear dataset helpful for picking dispersion curves.

This transformation eliminates all the ambient noise from human activities as well as source-generated noise.

5. Use of MASW in Construction Projects

Many researchers have correlated the MASW method with conventional geotechnical method such as standard penetration test, to determine shear wave velocity variation with depth and stiffness of subsurface material.

In this paper effort is made to provide cost and time effectiveness by adopting geophysical method of investigation MASW method, which will help to reduce the cost and time to some extent for a construction project. Being a geotechnical method of investigation, using this method will surely benefit the construction project work

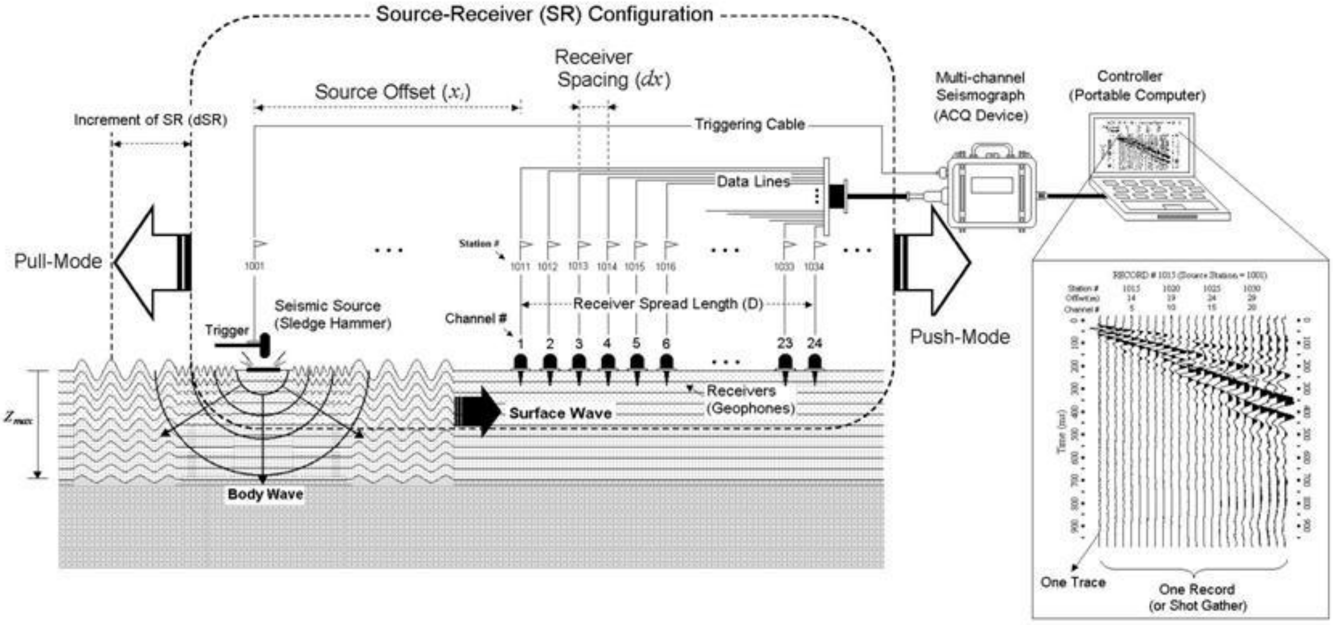

Figure 2: A typical MASW configuration [4]

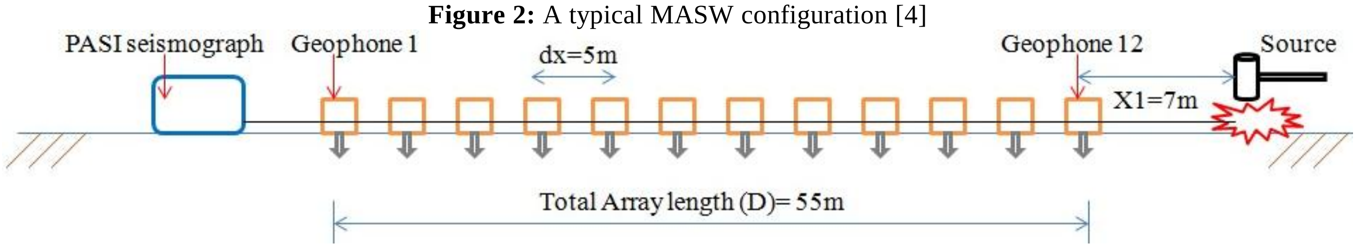

Figure 3: Setup of MASW on test site.

as construction managers, site engineers, planning engineers, estimation engineers will be helped to keep the cost of the project and to complete the project in time to some extent by using this method as shown in Table 2

The cost required to adopt the geotechnical method depends upon the type of the structures to be built. In general, the more the detailed investigations are done, the more is known about soil classification and stratification resulting in increase in cost. However, a limit is reached when the cost of investigation outweighs any saving in the cost of the project, and it increases the overall cost. It would not be economical to have investigation beyond that limit.

The cost varies between 0.05 to 0.2% of total cost of the entire project [2]. Whereas, in Geophysical method of MASW the aim is to get the maximum information that is useful in the design and construction of the project at a minimum cost.

The time required for Standard penetration test and Boring methods depends on the type of the structure to be executed and could extend in case of several factors such as drill rate, trip time, hole problems, casing running, directional drilling, completion type, move-in and move-out with the rig, weather etc. Each factor may vary with geology, geographical location, operator philosophy and efficiency.

Whereas, using MASW method the data can be acquired at a rate of 50-150 m/hr.

Table 2: Geotechnical method v/s MASW method [3]

Description	*Geotechnical Methods*		*MASW method*
	SPT	*CPT*	
Strain	Large	Large	Small
Drilling	Essential	Essential	No
Cost	High	High	Medium
Time	Long	Medium	Short
Quality of data	Good	Very good	Very good
Detection of variability of soil deposits	Good	Very good	Very good
Suitable soil type	Non gravel	Non gravel	All
Depth of information for microzonation	Good	Fair	Very good

6. Results and Discussion

6.1 Shear wave velocity (Vs).

The average shear wave velocity for current study area is 228 m/s. (Figure 4a).

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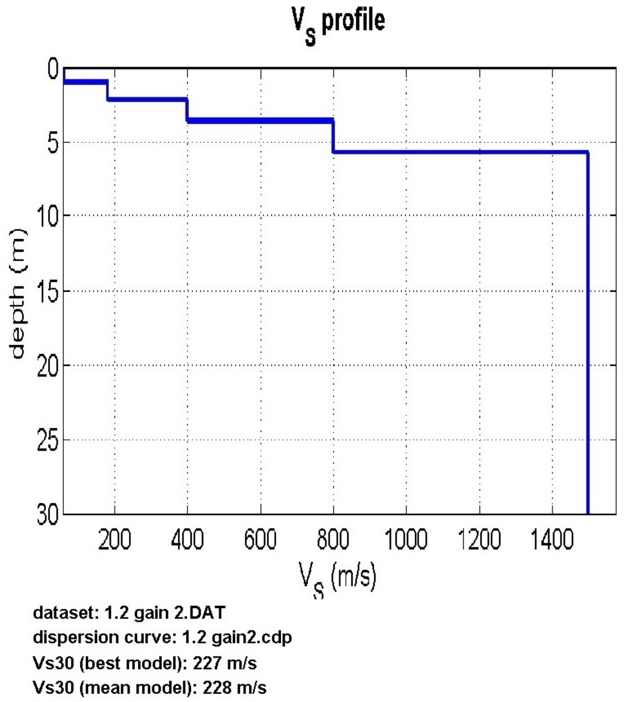

Figure 4a: Velocity variation with respect to depth.

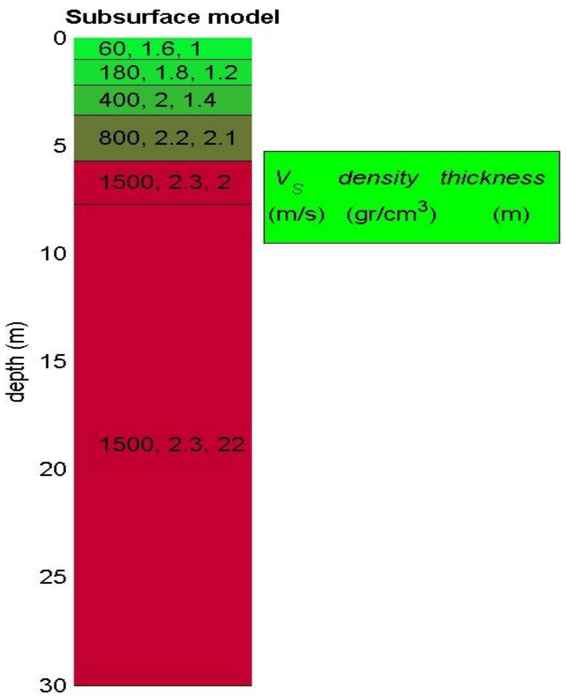

Figure 4b: Subsurface model.

The average shear wave velocity of soil for the Mumbai city is ranging from 110 to 350 m/s [6].

Subsurface profile model of the shear wave velocity variation with depth is modeled (Figure 4b) showing strata wise distribution.

Shear Wave Velocity of Soil is an important parameter in Site Classification according to NEHRP (National earthquake hazard reduction programme) and dynamic properties of soil. It has been found that the average shear wave velocity of Veermata Jijabai technological institute, college ground-test site is 228 m/s which indicates that the area of study falls under the site class D. There is presence of stiff soil beneath the surface as per NEHRP site classification. So, precaution should be taken while designing any new structures. Also taking readings by MASW gives the true nature of soil stratigraphy and subsurface profile for further investigations as per NEHRP soil classification.

It is found that in subsurface profile of ground the first layer is of soft soil upto 1.0 m, second layer is stiff soil for 1.2 m, third layer is very dense soil and soft rock for 1.4 m, fourth layer is rock particles for 2.1 m, fifth layer is hard rock at 5.7 m from ground surface.

6.2 Comparison of Time Required between Geotechnical Method and MASW Method.

Time required to complete one task job is very important as other successive tasks may be dependent on it. A primary process of site investigation becomes more important to know the engineering properties, index properties of soil structure and also the depth, thickness, extent of composition of each soil stratum, ground water table. This data is used by designers to design desired structure as per client requirement. It is observed that time required for Geotechnical investigation is more than the Geophysical investigation shown in Table 3 and Table 4. For Geotechnical investigation 5 boreholes upto 30 m depth are considered to be executed in 1500 sq.m area of current study which estimates a total of 24 days required to complete subsurface exploration programme and on the other hand Geophysical investigation can be completed in 3 days. So, for subsurface exploration a Geophysical investigation method is to be adopted. This method provides time efficiency to complete the project within the estimated duration.

By using project management software total duration required by both the methods is show in the Figure. 5.

The MASW method is non-invasive, by which it is not possible to determine the engineering and index properties of subsurface soil, but is used to determine the depth, thickness of subsurface strata, hard rock profile, and ground water table.

The shear velocity changes as per strata below the ground surface changes helpful to determine the ground stiffness. With the help of past records of geotechnical investigation of adjacent areas or nearby areas, engineering and index properties can be correlated with the current study area where geotechnical method is not adopted.

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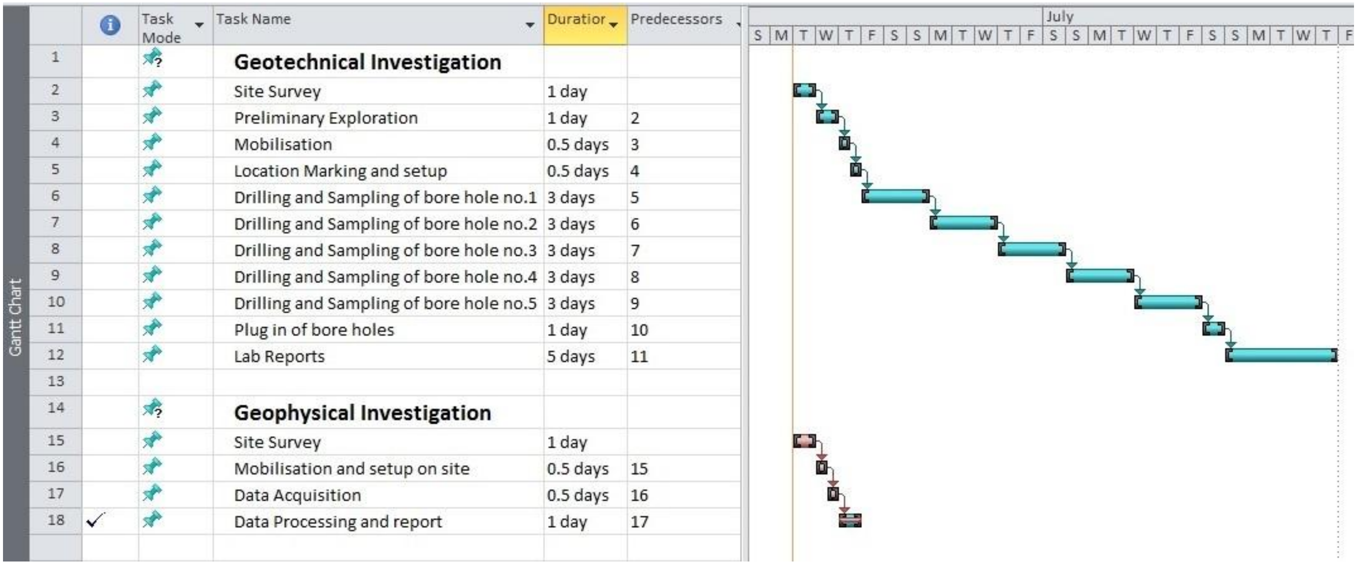

Figure 5: Geotechnical and Geophysical investigation - schedule of work

Table 3: Time required for Geotechnical Investigation

Sr. No.	*Geotechnical method*	*Time (days)*
1	Site Survey	1
2	Preliminary Exploration	1
3	Mobilization	0.5
4	Location marking and setup on site	0.5
5	Drilling and sampling of borehole no.1	3
6	Drilling and sampling of borehole no.2	3
7	Drilling and sampling of borehole no.3	3
8	Drilling and sampling of borehole no.4	3
9	Drilling and sampling of borehole no.5	3
10	Plug in of boreholes	1
11	Lab reports	5
Total days of work		24

Table 4: Time required for Geophysical investigation

Sr. No.	*Geophysical method*	*Time (days)*
1	Site Survey	1
2	Mobilization and setup on site	0.5
3	Data acquisition	0.5
4	Data processing and report	1
Total days of work		3

6.3 Comparison of Cost Required between Geotechnical Method and MASW Method.

The cost of investigation estimated is for execution of the work only [7]. The cost excludes procurement of materials or equipments. It is considered that the soil investigation is done by the contractor or agency.

Cost required for investigation is shown in Table 5 and Table 6, by which cost effectiveness is achieved by adopting Geophysical MASW method.

Table 5: Cost required for MASW method

Item Description	*Cost (Rs/day)*	*Cost for current study*
Site Survey	5000	5000
Data acquisition	20000	20000
Data processing and report	20000	20000
Total cost for MASW method		45000/-

Table 6: Cost required for Conventional Geotechnical method [7]

Sr. No	*Geotechnical Method*				
	Item description	*Unit*	*Cost in Rs*	*Cost of 5 bore holes required for current study*	*Remark*
1.	Bore with shell and auger or by percussion method in soil other than rock				
	i) Not exceeding 5 m	m	550	9900	upto 3.6 m
2.	Rotary core drilling in rock and to take continuous rock cores				
	i) Not exceeding 5 mtr	m	1000	7000	from 3.6 m to 5 m
	ii) Between 5 m and 10 m	m	1100	27500	
	iii) Between 10 m and 15 m	m	1200	30000	
	iv) Between 15 m and 20 m	m	1300	32500	
	v) Between 20 m and 25 m	m	1400	35000	
	vi) Between 25 m and 30 m	m	1500	37500	
	Take Disturbed samples	each	200	3000	3 samples each bore hole
	Take Undisturbed samples	each	250	12500	10 samples each bore hole
3.	Carry out standard penetration test	each	250	5000	for 4 'N' values of each bore
Total Cost required for geotechnical type of investigation				199900/-	

7. Conclusion

a) As MASW is a non-invasive technique allowed for the estimation of the Vs ground profile, measuring of shear waves can be done in a time efficient and cost effective manner compared to the invasive technique helpful for Construction Project work.
b) As seen the average shear wave velocity of Veermata Jijabai Technological Institute, ground-test site is 228 m/s which indicates that the area of study falls under the site class D according to NEHRP site class.
c) Subsurface profile and top of bedrock is determined using this MASW method compared to conventional methods which requires more time and cost.
d) The MASW method saves time and cost for the investigation and proves useful for construction project work.

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