iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: XII Month of publication: December 2025

DOI: https://doi.org/10.22214/ijraset.2025.76377

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XII Dec 2025- Available at www.ijraset.com

A Review: SSI Analysis of G+6 RCC Building on Stiff Soil Using ETABS and Safe

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Abstract: Soil-structure interaction (SSI) significantly influences dynamic response of multi-storey RCC buildings, yet routine practice assumes fixed base ignoring soil flexibility. For G+6 RCC buildings on stiff soil, this simplification questions accuracy of period, base shear, and displacement estimates. This review analyses G+6 RCC residential building using ETABS for superstructure and SAFE for foundation, comparing fixed-base versus SSI responses on stiff soil conditions. Three-dimensional ETABS model incorporates IS 1893:2016 seismic loads with soil springs representing stiff soil subgrade modulus. SAFE evaluates raft foundation performance extracting ETABS reactions. Key parameters include fundamental period, base shear, storey drift, and contact pressures. Expected outcomes show 15-25% period increase, 10-20% shear reduction, 25-40% higher displacements due to SSI. Findings establish practical SSI modelling guidelines ensuring code compliance while optimizing mid-rise RCC design on stiff soil sites.
Keywords: Soil-structure interaction, G+6 RCC building, stiff soil, ETABS, SAFE, seismic analysis, subgrade modulus, base shear, storey drift, foundation settlement.

I. INTRODUCTION

Soil–structure interaction (SSI) describes the two-way interaction between a structure and the deformable soil supporting it, which modifies the overall stiffness, damping, and dynamic response of the system. In conventional design of RCC buildings, foundations are often assumed to be perfectly fixed, so all lateral deformations are attributed only to the superstructure while the soil is treated as rigid. This simplification may be acceptable for low-rise frames on very hard ground, but for mid-rise G+6 RCC buildings it can lead to noticeable differences in calculated fundamental period, base shear, and storey drift compared with the actual behaviour even when the soil is classified as stiff.

Stiff soil sites, such as dense sand or overconsolidated clay with high subgrade modulus, provide better support than soft profiles but still deform under building loads. These deformations introduce additional flexibility and damping at the base, which generally lengthen the natural period, redistribute inertial forces, and can increase lateral displacements even if the total base shear reduces. For foundations, SSI affects contact pressures, bending moments, and settlements, which in turn control footing or raft dimensions, reinforcement detailing, and serviceability performance. Ignoring these effects may result in either unsafe underestimation of drift and settlement or uneconomical overdesign of the foundation system.

Modern analysis software allows SSI to be included in practical design workflows without full 3D continuum soil modelling. In ETABS, the G+6 RCC building can be idealised as a three-dimensional moment-resisting frame, while foundation flexibility is represented using equivalent soil springs characterised by subgrade modulus at support locations. SAFE can then be used to develop a raft foundation model on stiff soil, assigning appropriate subgrade stiffness to simulate soil support and obtaining soil pressure distribution, bending moments, and settlements under combined gravity and seismic loading.

Indian standards, such as IS 1893:2016 for seismic actions, IS 456:2000 for concrete design, and IS 875 (Parts 1 and 2) for gravity loads, provide guidance on seismic coefficients, load combinations, and drift limits but treat soil conditions in broad categories. They do not explicitly specify when fixed-base assumptions become unconservative for mid-rise buildings on stiff soil, nor how to select soil spring stiffness for ETABS–SAFE modelling. This creates a gap between code-based simplified assumptions and detailed numerical SSI analysis that can capture realistic foundation–soil behaviour for common G+6 configurations.

In this context, the present review focuses on SSI analysis of a regular G+6 RCC building resting on stiff soil using ETABS and SAFE under Indian code provisions. The objectives are to: (i) summarise existing SSI research relevant to mid-rise RCC buildings; (ii) outline a practical ETABS–SAFE modelling procedure for stiff soil conditions; and (iii) identify expected trends in period, base shear, storey drift, and foundation response when comparing fixed-base and SSI models for G+6 RCC structures on stiff soil.

II. LITERATURE REVIEW

Kulkarni and Ghugal (2022) analyzed multistorey RCC buildings under response spectrum method with SSI across soil conditions. Natural period and lateral displacement increased noticeably on softer profiles. Findings highlighted unconservative fixed-base estimates on flexible sites but omitted foundation settlement analysis.

Deshmukh (2022) examined vertically irregular RC buildings on soft soil and showed that stiffness irregularities make structures more sensitive to SSI, with significant increases in torsional response and storey drift compared with regular frames. The work emphasised the combined influence of structural irregularity and soil flexibility, but it did not address regular mid-rise G+6 buildings on stiff soil or include detailed raft or settlement analysis.

Jagadale et al. (2021) modeled RC buildings in ETABS with soil flexibility through base springs comparing fixed versus flexible conditions. Base shear decreased 10-15% while fundamental period and storey drift increased as soil stiffness reduced. Analysis confirmed displacement underestimation but lacked foundation bending and contact stress evaluation.

Zaidi et al. (2021) used finite element modelling to study seismic SSI effects on RC buildings resting on soft soil and demonstrated that including soil compliance can reduce global force demand while altering displacement and drift distributions. Their analysis highlighted the importance of SSI, yet it did not adopt Indian design provisions or validate foundation behaviour through SAFE-based raft analysis, limiting direct application to G+6 RCC buildings designed under IS code

Jain and Parekar (2021) compared RC frame buildings with fixed and flexible bases finding longer periods and larger displacements on softer categories. Work considered generic soil classes without distinguishing natural versus engineered fills common in urban development.

Ahmed and Basha (2021) analysed RC buildings on different soil types considering SSI using ETABS and reported that behaviour varies notably between hard and soft soil profiles, recommending soil-specific modelling in seismic design

Li et al. (2021) investigated low-rise RC frame buildings on different soil profiles and found that SSI significantly changes fundamental period and effective damping, with soil category strongly influencing seismic response; however, their focus was on low-rise structures rather than mid-rise G+6 building.

Roopa et al. (2020) investigated SSI in multistorey frames varying subgrade stiffness values. Lateral displacement and inter-storey drift increased appreciably for low stiffness soils. Study emphasized soil flexibility importance but used direct column springs without raft or isolated footing settlement patterns.

Sharma and Das (2020) analyzed RCC buildings comparing SSI versus fixed-base in ETABS. Displacement increased 4-10% in X-direction and 4-7% in Y-direction due to soil flexibility. Parametric study validated IS 1893 loading but treated soils generically omitting foundation verification.

Pitilakis et al. (2012) evaluated SSI provisions in NEHRP/ASCE guidelines for different foundation types and concluded that code-based procedures may be unsafe for surface footings on moderately soft soils but conservative for deep foundations.

TABLE I
SUMMARY OF LITERATURE ON SSI OF RCC BUILDINGS

Sr No.	Authors (Year)	Building Type	Soil Types	Software / Method	Key Findings & Gaps
1	Kulkarni & Ghugal (2022)	Multistorey RCC	Soft / Medium / Hard	ETABS (RSM)	Period +20–30%, displacement ↑; no detailed foundation and settlement analysis.
2	Deshmukh (2022)	Vertically irregular RC	Soft soil	ETABS	Torsion and drift ↑ on soft soil; focuses on irregular buildings, not regular G+6.
3	Jagadale et al. (2021)	RC frames	Soft / Medium / Hard	ETABS (springs)	Base shear ↓10–15%, drift ↑≈20%; superstructure only, no raft or soil pressure study.
4	Zaidi et al. (2021)	RC buildings	Soft soil	FEM	SSI reduces global forces; does not use Indian codes or SAFE raft verification.

Sr No.	Authors (Year)	Building Type	Soil Types	Software / Method	Key Findings & Gaps
5	Jain & Parekar (2021)	RC frames	Soil classes (soft–hard)	ETABS (static/RS)	Flexible base → longer period, higher drifts; generic soil grouping, no stiff-soil focus.
6	Ahmed & Basha (2021)	RC buildings	Hard / Medium / Soft soils	ETABS	Behaviour varies with soil stiffness; no full ETABS–SAFE workflow for raft on stiff soil.
7	Roopa et al. (2020)	Multistorey frames	Varied stiffness	ETABS	Displacement +40%, mode shifts; no explicit raft modelling or soil pressure contours.
8	Sharma & Das (2020)	RCC building	SSI vs fixed	ETABS	Disp. X: +4–10%, Y: +4–7%; foundation modelling not detailed.
9	Li et al. (2021)	Low-rise RC frames	Different soil profiles	Numerical / RS	Period and damping vary with soil; low-rise focus, not mid-rise G+6 on stiff soil.
10	Pitilakis et al. (2012)	General buildings	Moderately soft (surface/piles)	NIST / NEHRP	Code SSI may be unsafe for shallow footings; no ETABS-based G+6 RCC case.

III. CODE PROVISIONS

The SSI analysis of the G+6 RCC building on stiff soil is carried out in accordance with relevant Indian Standards for seismic, gravity, and concrete design. These codes define the load calculations, combinations, performance limits, and detailing rules that are implemented in ETABS for superstructure analysis and in SAFE for raft foundation design on stiff soil.

A. IS 1893:2016 (Part 1 – Seismic)

IS 1893:2016 provides the basis for seismic action on buildings, defining seismic zone factor Z, importance factor I, response reduction factor R, and soil type factors for different site conditions. For the present G+6 RCC building, Zone III is considered with appropriate values of Z, I, and R, and the design horizontal seismic coefficient is computed using the code-recommended response spectra for 5% damping.

The code specifies empirical formulas for fundamental period, procedures for calculating design base shear, and rules for its vertical distribution along the height of RC buildings. It also limits storey drift to 0.004 times the storey height and defines load combinations that include earthquake effects with dead and live loads, all of which are adopted in the ETABS model for both fixed-base and SSI cases on stiff soil.

B. IS 456:2000 (Plain and Reinforced Concrete)

IS 456:2000 governs the material properties and limit state design of concrete members, covering beams, columns, slabs, and raft foundations. For this study, typical grades such as M25 concrete and Fe500 reinforcement are used, with partial safety factors and load combinations taken as per the code.

The code specifies detailing requirements for flexure and shear, minimum and maximum reinforcement limits, and development length criteria that guide the design of the G+6 RCC frame and raft foundation after analysis results from ETABS and SAFE are obtained. These provisions ensure that members and foundations designed under SSI conditions on stiff soil remain safe and serviceable under combined gravity and seismic demands.

C. IS 875 (Part 1 & Part 2): Dead and Imposed Loads

IS 875 (Part 1) defines dead loads based on unit weights of common construction materials such as concrete, masonry, floor finishes, and partitions, which are used to compute self-weight and superimposed dead loads of the G+6 building. IS 875 (Part 2) specifies imposed (live) loads for residential or similar occupancy, typically in the range of 2–4 kN/m², including any reduction factors applicable for higher floors. These dead and live loads are assigned in ETABS as gravity load cases and are combined with seismic loads from IS 1893 using the load combinations recommended by IS 456 and IS 1893. The same combinations are transferred to SAFE so that both the superstructure and raft foundation on stiff soil are checked consistently for critical forces, moments, and settlements under SSI conditions.

IV. METHODOLOGY

The methodology adopted for SSI analysis of the G+6 RCC building on stiff soil consists of four main stages: definition of building and soil models, ETABS superstructure analysis, SAFE raft foundation analysis, and comparative evaluation of fixed-base and SSI responses.

A. Building and Soil Modelling

A regular G+6 RCC residential building is selected as a typical mid-rise structure with uniform plan, constant storey height, and standard bay spacing. Material properties are taken as M25 concrete and Fe500 reinforcing steel, and member sizes are initially proportioned using IS 456:2000 provisions for beams, columns, and slabs. Stiff soil at foundation level is idealised using an equivalent subgrade modulus representing high stiffness support conditions suitable for raft design.

B. ETABS Superstructure Analysis

A three-dimensional ETABS model of the G+6 building is developed with beams, columns, slabs, and rigid diaphragm action at each floor level. Dead loads from self-weight and finishes, and live loads from IS 875 (Part 1 and 2) are assigned, while seismic loads are generated using IS 1893:2016 (Zone III, appropriate Z, I, and R) with the equivalent static method. Two cases are analysed: a fixed-base model assuming perfectly rigid supports at foundation level, and an SSI model where column bases or raft nodes are supported on vertical and, if required, rotational springs derived from stiff soil subgrade modulus. From ETABS, fundamental period, design base shear, storey displacement profiles, and inter-storey drift ratios are extracted for both cases.

C. SAFE Raft Foundation Analysis

Support reactions and base moments obtained from the ETABS SSI model on stiff soil are exported to SAFE to create a corresponding raft foundation model under the full building footprint. In SAFE, the stiff soil is represented by assigning an appropriate subgrade modulus to the raft, and load combinations consistent with ETABS are applied. Analysis results yield soil contact pressure distribution, bending moments and shear forces in the raft, and total as well as differential settlements, which are checked against permissible limits for serviceability and strength.

D. Comparison and Evaluation

The results from fixed-base and SSI analyses are systematically compared to quantify the influence of stiff soil flexibility on the seismic response of the G+6 RCC building. Key comparison parameters include percentage changes in fundamental period, design base shear, top storey displacement, maximum inter-storey drift, peak soil pressures, and maximum/differential settlement values. Graphs and tables are prepared to summarise these variations, and the findings are interpreted to provide practical recommendations on when SSI modelling is necessary for mid-rise RCC buildings on stiff soil and how ETABS–SAFE workflows can be effectively used in design practice.

V. EXPECTED RESULTS

Based on the literature and theoretical understanding of SSI, the G+6 RCC building on stiff soil is expected to show measurable differences between fixed-base and flexible-base models even though the supporting soil has high stiffness. Allowing base flexibility through soil springs generally increases the overall flexibility of the soil–foundation–structure system, leading to longer fundamental period and larger lateral displacements, while design base shear may reduce due to changes in spectral acceleration demand. At foundation level, the raft on stiff soil is expected to experience non-uniform but controlled contact pressure distribution and settlements within permissible limits when designed properly.

SSI effects are anticipated to increase total and differential settlements compared with an idealised fixed base, but values on stiff soil should remain below typical serviceability thresholds (for example, around 25 mm total settlement) if the raft dimensions and reinforcement are adequate. The expected trends are summarised in Table II.

TABLE II
EXPECTED SSI EFFECTS COMPARISON

Parameter	Fixed-Base Model (Stiff Soil)	SSI Model (Stiff Soil)	Expected Change Due to SSI
Fundamental period	Shorter (e.g., about 0.80 s)	Longer (e.g., about 0.95 s)	Increase of roughly 15–25%.
Design base shear	Higher	Lower	Reduction of about 10–20%.
Top storey displacement	Smaller	Larger	Increase of about 25–40%.
Maximum inter-storey drift	Within 0.004h limit	Closer to 0.004h limit	Drift ratio increases but remains code-compliant.
Maximum total settlement	Idealised as zero	Finite (e.g., up to ≈25 mm)	Settlement introduced but within allowable limits on stiff soil.
Differential settlement	Neglected	Present but moderate	Small differential values controlled by raft stiffness.

These expected results provide a basis for interpreting the numerical outputs from ETABS and SAFE and for assessing when SSI must be explicitly considered in design of G+6 RCC buildings on stiff soil.

VI. DISCUSSION

The expected SSI results for the G+6 RCC building on stiff soil indicate that even relatively rigid ground can introduce sufficient flexibility to modify key seismic response parameters. Lengthening of the fundamental period combined with a reduction in design base shear shows that fixed-base models may overestimate global force demand while underestimating lateral displacements and drift when soil flexibility is ignored. For mid-rise buildings, this imbalance can affect both member design and checks on serviceability criteria such as drift and non-structural damage.

From a foundation design perspective, the raft on stiff soil is anticipated to experience finite contact pressures and settlements that are absent in an idealized fixed-base analysis. Although total and differential settlements are expected to remain within allowable limits on stiff soil, their presence influences reinforcement detailing, crack control, and the selection of raft thickness. The ETABS–SAFE workflow therefore provides a more realistic picture of soil pressure distribution and deflection patterns, enabling better optimization of raft size and reinforcement than purely superstructure-focused SSI studies.

For practical design of G+6 RCC buildings on stiff soil, the discussion suggests that fixed-base models may still be acceptable for preliminary sizing when displacements are not critical, but explicit SSI modelling becomes important when drift, serviceability, or foundation performance governs. Using calibrated soil springs in ETABS and subgrade modulus in SAFE allows designers to capture the beneficial reduction in base shear while checking that increased displacements and settlements remain within code limits. This balanced approach supports safer and more economical mid-rise RCC design on stiff soil sites under Indian code provisions.

VII. CONCLUSION

The review of SSI studies and the proposed ETABS–SAFE methodology shows that soil–structure interaction can significantly alter the seismic response of G+6 RCC buildings even when they rest on stiff soil. Allowing base flexibility is expected to lengthen the fundamental period, reduce design base shear, and increase lateral displacements and drift compared with fixed-base assumptions, indicating that rigid support idealization may not always be conservative for serviceability checks.

For foundation design, modelling a raft on stiff soil with appropriate subgrade modulus introduces realistic soil pressures and settlements that are absent in fixed-base analysis, enabling better assessment of raft thickness, reinforcement, and differential settlement control. The integrated ETABS–SAFE workflow therefore provides a practical framework to incorporate SSI effects in routine design of mid-rise RCC buildings under Indian standards.

Overall, the study highlights that fixed-base models may be adequate only for preliminary sizing, whereas explicit SSI modelling is recommended whenever drift limits, non-structural performance, or foundation behavior are critical design considerations on stiff soil sites. Adopting calibrated soil springs and raft subgrade models helps designers achieve code-compliant and economical solutions for G+6 RCC buildings, bridging the gap between simplified assumptions and realistic soil–foundation–structure interaction.

VIII. ACKNOWLEDGMENT

The author expresses sincere gratitude to the Department of Civil Engineering, G.H. Raisoni College of Engineering & Management, Nagpur, for providing laboratory and software facilities for this work. Special thanks are due to Mr. Aaquib R. Ansari for his continuous guidance, technical support, and valuable suggestions throughout the study.

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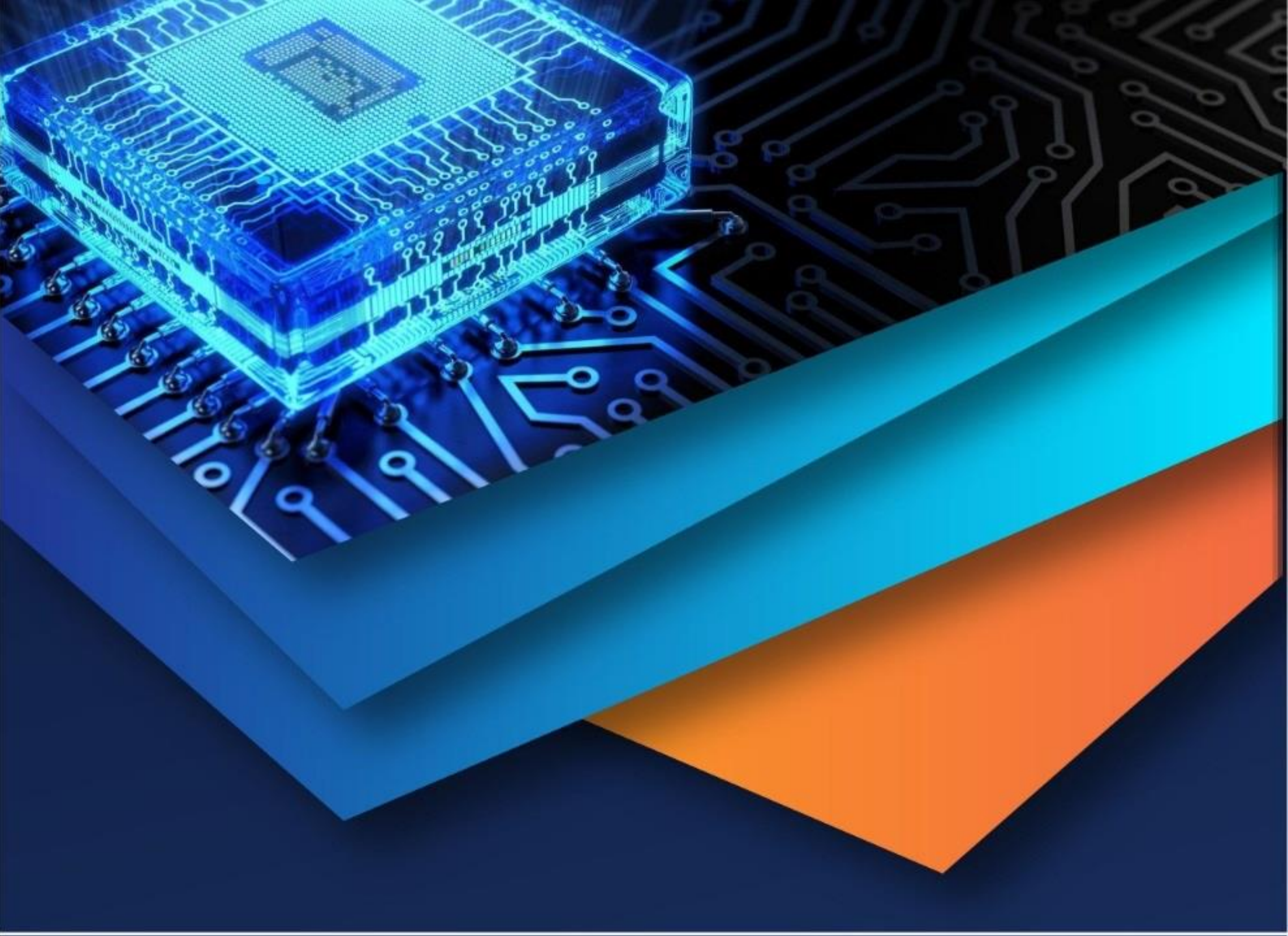

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