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Effect of Diaphragm Discontinuity in the Seismic Response of Multi-Storeyed Building

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Abstract:
Many buildings in the present scenario have irregular configurations both in elevation and plan. This in future may subject to devastating earthquakes. It is necessary to identify the performance of the structures to withstand against disaster for both new and existing buildings. Now a days openings in the floors is common for many reasons like stair cases, lighting architectural etc., these openings in diaphragms cause stresses at discontinues joints with building elements. Discontinuous diaphragms are designed without stress calculations and are thought-about to be adequate ignoring any gap effects. In this thesis an attempt is made to try to know the difference between a building with diaphragm discontinuity and a building without diaphragm discontinuity.

Keywords:
Seismic analysis, diaphragm discontinuity, nonlinear analysis, pushover analysis, time history analysis.

INTRODUCTION:
1.1 BACKGROUND:
In multistoreyed framed building, damages from earthquake generally initiates at locations of structural weaknesses present in the lateral load resisting frames. This behaviour of multi-storey framed buildings during strong earthquake motions depends on the distribution of mass, stiffness, strength in both the horizontal and vertical planes of buildings. In few cases, these weaknesses may be created by discontinuities in stiffness, strength or mass along the diaphragm. Such discontinuities between diaphragms are often associated with sudden variations in the frame geometry along the length of the building. Structural engineers have developed confidence in the design of buildings in which the distributions of mass, stiffness and strength are more or less uniform. There is a less confidence about the design of structures having irregular

1.2OBJECTIVES:
A detailed literature review is carried out to define the objectives of the thesis. The literature review is discussed in detail in Chapter 2 and briefly summarized as follows:

i) International Building Code (IBC) suggests that for buildings with diaphragm separation, the code prescribes a rise of twenty five percent within the design forces found for connections of diaphragms.
ii) American Concrete Institute Building Code, I 318-08 doesn't address the result of a gap on the floor.
iii) ASCE 7-05, Section 12.3.1.2, permits diaphragms of RCC slabs or concrete crammed metal decks with span-to-depth ratios of 3:1 or less.
iv) Nakashima et al. analyzed a multi storey RC building using non-linear analysis last that the inclusion of diaphragm flexibility failed to considerably modification the particular amount of the structure and therefore the most total base shear.

1.3 SCOPE OF THE PRESENT STUDY:
In the present study, a typical multi storey building is analyzed using commercial software SAP2000 for nonlinear static (pushover) and dynamic (time history) analysis. All the analyses has been carried out considering and ignoring the diaphragm discontinuity and the results so obtained have been compared.

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This study is done for RC framed multistory building with fixed support conditions. The results of this report is based on one case-study.

1.4METHODOLOGY:

a) A thorough literature review to understand the seismic evaluation of building structures and application of pushover analysis and time history analysis.
b) Select an existing building with diaphragm discontinuity.
c) Design the building as per prevailing Indian Standard for dead load, live load, and earthquake load.
d) Analyze the building using linear/nonlinear static/dynamic analysis methods.
e) Analyze the results and arrive at conclusions.

LITERATURE REVIEW:

2.1 GENERAL:

To provide a detailed review of the literature related to diaphragm discontinuity in its entirety would be difficult to address here. A brief review on diaphragm discontinuity of previous studies is presented here. This literature review focuses on recent contributions related to diaphragm and past efforts most closely related to the needs of the present work.

2.2 LITERATURE REVIEW:

International Building Code-2006, needs the diaphragm with unexpected discontinuities or variations in stiffness, also those having cutout or open areas greater than 50 percent of the gross enclosed diaphragm area, or change in effective diaphragm stiffness of over 50 percent from one story to consequent, to be considered as irregular in plan. For structures with this diaphragm discontinuity, the code prescribes a rise of twenty five % within the design forces determined for connections of diaphragms to vertical components. The code doesn't attribute any criteria touching on the diaphragm style itself.

2.3 CONCLUSION:

Here a question arises that what will the effect if the same building is designed with diaphragm discontinuity and without diaphragm discontinuity. It is studied in this project.

MODELLING OF BUILDING:

3.1 INTRODUCTION:

In this project we are studying a multi storeyed building with diaphragm discontinuity and without diaphragm discontinuity as model-1 and model-2 respectively. The building is modeled and designed in STAAD-Pro from which reinforcing details were drawn. Further the building is modeled in SAP2000 with the above obtained reinforcing details in which pushover analysis and time history analysis are performed.

3.2 DETAILS OF SELECTEDBUILDING:

For the study purpose, an existing building plan in Berhampur was taken which is meant for hospital. Even though this area is in seismic zone II, it is taken as zone V for study purpose. Building details are given below.

Table 3.1 Details of the building

Building Parameters	Details
Plan size	39.20m × 40.20m
Location	Berhampur, Odisha
Usage	Hospital Building
Building height	17.50m (G+4)
Grade of Steel	Fe 415
Grade of Concrete	M-20
Seismic Zone*	V (PGA = 0.36g)
Column size	300×500
Beam sixe	300×500
Slab thickness	120mm
Outside wall thickness	230mm
Partition wall thickness	230mm
Live load	3kN/[illegible] slabs and 2kN/[illegible] roof

3.3DESIGN OF THE BUILDING:

Initially the building was modelled and designed in STAAD-Pro from which reinforcing details were drawn. Further the building is modeled in SAP2000 with the above obtained reinforcing details. The load combinations are shown below.

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- COMB1 = 1.5 (DEAD + LIVE)
- COMB2 = 1.2 (DEAD + LIVE + EQ)
- COMB3 = 1.2 (DEAD + LIVE - EQ)
- COMB4 = 1.5 (DEAD + EQ)
- COMB5 = 1.5 (DEAD - EQ)
- COMB6 = 0.9 DEAD + 1.5 EQ
- COMB7 = 0.9 DEAD - 1.5 EQ

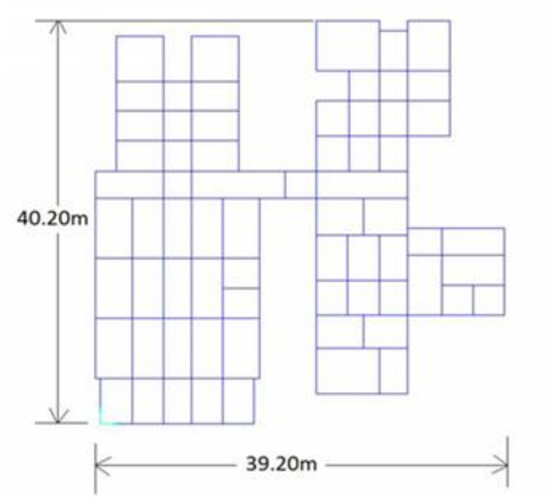

Fig 3.1 Plan of the building

The Fig. 3.1 shows the plan of the building that is studied in this thesis Fig. 3.2 shows the frame layout and Fig. 3.3 shows 3D model of the building. These figures were drawn using SAP2000.

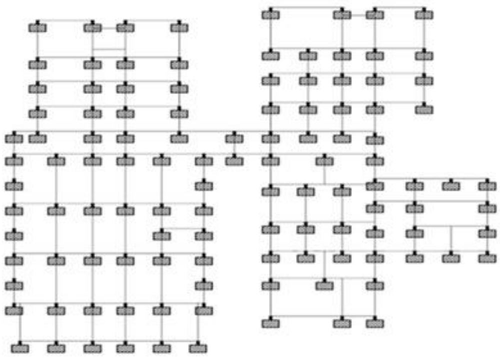

Fig 3.2 Typical frame layout

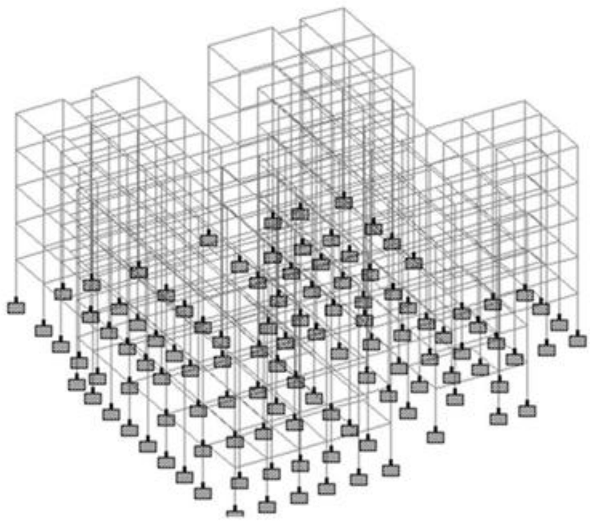

Fig 3.3 Computer model of the building

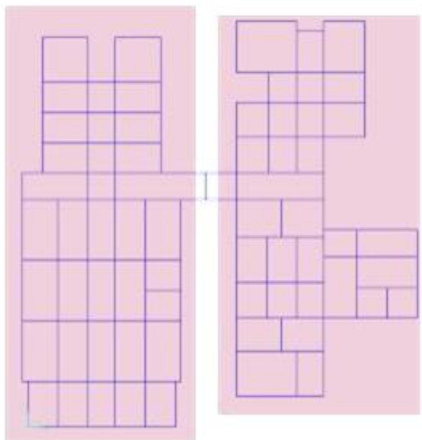

Fig 3.4 Model – 1 (with discontinuous diaphragm)

In model-1 (Fig. 3.4) the building is divided into two diaphragms. Loads are assigned separately to each diaphragm and the building is analyzed. The pushover curves and hysteresis loops are shown for this building in the last chapter.

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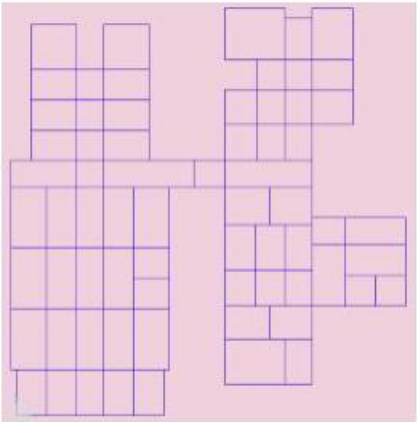

Fig 3.5 Model – 2 (with continuous diaphragm)

In model-2 (Fig. 3.5) the building is taken as a whole i.e., single diaphragm. Loads are assigned to the complete building as a single diaphragm and the building is analyzed. The pushover curves and hysteresis loops are shown for this building in the last chapter.

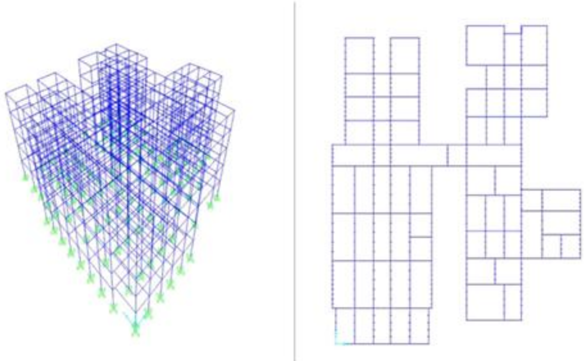

Fig 3.6 Building Model in SAP-2000

PUSHOVER ANALYSIS:

4.1 INTRODUCTION:

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. A plot of total base shear versus top displacement in a structure is obtained by this analysis that would indicate a premature failure or weakness. All the beams and columns which reach yield or have experienced crushing and even fracture are identified. A plot of total base shear versus inter - story drift is also obtained.

A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, that shows the inertial forces which would be experienced by the structure when subjected to ground motion. Under incrementally increasing loads many structural elements may yield sequentially. Therefore, at each event, the structure experiences a decrease in stiffness. Using a nonlinear static pushover analysis,a representative non-linear force displacement relationship can be obtained.

4.2 Limitations:

Although pushover analysis has certain advantages in comparison to elastic analysis techniques, underlying various assumptions, the accuracy of pushover predictions and the restrictions of current pushover procedures must be recognized. The estimation of target displacement, selection of the lateral load patterns and identification of failure mechanisms due to higher modes of vibration are vital issues that have an effect on the accuracy of pushover result. Target displacement is global displacement likely in a design earth quake.

In pushover analysis, target displacement for a multi degree of freedom system is generally estimated similar to the displacement demand for corresponding equivalent single degree of freedom system. The fundamental properties of an equivalent SDOF system are gotten from a shape vector that represents the deflected shape of MDOF system. Most researchers recommend using the normalized displacement profile at target displacement level as a shape vector, but since this displacement is not known beforehand, an iteration is needed. Therefore, by most of the approaches, a fixed shape vector, elastic first mode, is utilized for simplicity without regarding higher modes. The target displacement is found by the roof displacement at mass center of the structure.

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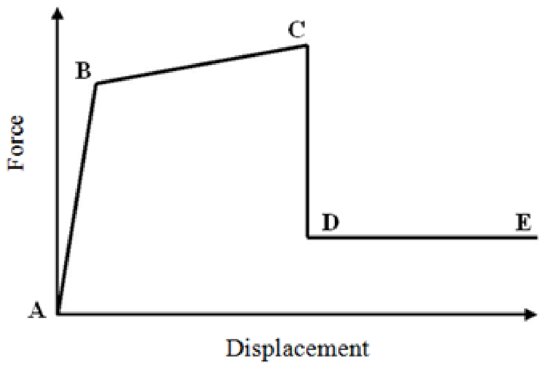

Fig 4.1 Force-Deformation for pushover hinge

In order to obtain performance points as well as the location of hinges in different stages, we can use the pushover curve. In this curve, the range AB the elastic range, B to IO the range of instant occupancy, IO to LS the range of life safety and LS to CP the range of collapse prevention. When a hinge touches point C on its force-displacement curve then that hinge must start to drop load. The manner in which the load is released from a hinge that has reached point C is that the pushover force or the base shear is reduced till the force in that hinge is steady with the force at pint D.

a) Immediate Occupancy – Achieves elastic behavior by limiting structural damage (e.g., yielding of steel, significant cracking of concrete, and nonstructural damage.)

b) Life Safety - Limit damage of structural and nonstructural components to minimize the risk of injury or casualties and to keep essential circulation routes accessible.

c) Collapse Prevention – Ensure a small risk of partial or complete building collapse by limiting structural deformations and forces to the onset of strength and stiffness degradation.

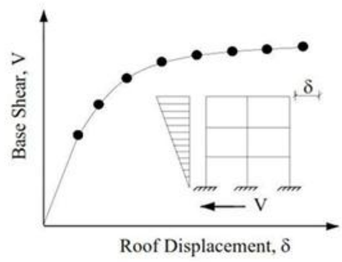

Fig 4.2 Global capacity (Pushover) curve

TIME HISTORY ANALYSIS:

5.1 INTRODUCTION:

Time-history analysis is a step-by-step analysis of the dynamical response (in time domain) of a structure subjected to a specified ground motion. This section explains the nonlinear parameters, input ground motion, time integration and damping used in the present study. The dynamic input has been given as a ground acceleration time-history that was applied uniformly in any respect points of the base of the structure. Computer software SAP2000 was used for carrying out nonlinear time-history analysis. 'Hilber-Hughes-Taylor alpha' (HHT) method was used for performing direct-integration time-history analysis. The HHT method is an implicit method and is popular due to its intrinsic stability. The HHT method uses a single parameter (alpha) whose value is bounded by 0 and - 1/3.

5.2 NATURAL RECORD OF EARTHQUAKE GROUND MOTION:

Natural ground acceleration time histories have been used for the dynamic analysis of the structural models. All these acceleration data were imported from SAP2000 and were scaled to have peak ground accelerations 0.36g. In the current project ground motion is taken from Century city- Lacc north at 0 degrees. 3000 points of acceleration data equally spaced at 0.02 sec was taken. So, total duration is 3000×0.02= 20 sec.

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5.3 HYSTERESIS LOOP:

Hysteresis is the dependence of the output of a system on its current input, and also on its history of past inputs. The dependence arises because the history affects the value of an internal state. To predict its future outputs, either its history or its internal state must be known. If a given input alternately increases and decreases, a typical mark of hysteresis a loop as in the figure 5.1 is forms.

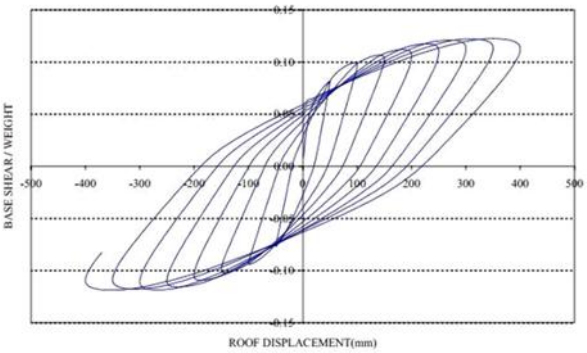

Fig. 5.1 Hysteresis loop

Such loops may occur because of a dynamic lag between input and output. This effect disappears as the input changes more slowly. This effect meets the description of hysteresis given above, but is often referred to as rate-dependent hysteresis to distinguish it from hysteresis with a more durable memory effect.

In structural engineering, hysteresis refers to the path-dependence of the structure's restoring force versus deformation. The physical reasoning behind this behavior is the softening of connection joints. The hysteresis loops of a structure offer vital information about the forces that act upon it and the resulting deformations. It is imperative to accurately map hysteresis curves since they play a pivotal role in creating a better nonlinear model. Fortunately, many of the commercial products that provide nonlinear analyses have the option to input a hysteresis model. The hysteretic behavior of a structure plays a crucial role in many current approaches to seismic performance-based analysis and design. As a result, many experiments have been conducted to record hysteretic data for shear walls and other subassemblies.

Extraction of hysteretic characteristics of frame building components can lead to an understanding of the structure's degradation and nonlinear response range. The process involves the construction of a hysteresis curve by plotting time history pairs of restoring force across the component (on the vertical axis), and relative displacement across the component (on the horizontal axis).

RESULTS AND DISCUSSIONS:

6.1. MODAL PROPERTIES:

Table 6.1: Mass participation ratio for first 12 modes of the Buildings

Mode	Model-1			Model-2		
	Period	UX	UY	Period	UX	UY
1	1.18	0.00	0.86	0.52	0.00	0.86
2	1.03	0.00	0.00	0.46	0.00	0.00
3	0.88	0.84	0.00	0.39	0.84	0.00
4	0.76	0.00	0.00	0.34	0.00	0.10
5	0.70	0.00	0.00	0.31	0.00	0.00
6	0.39	0.00	0.10	0.17	0.10	0.00
7	0.38	0.00	0.00	0.10	0.00	0.03
8	0.29	0.00	0.00	0.09	0.00	0.00
9	0.28	0.10	0.00	0.08	0.00	0.01
10	0.28	0.01	0.00	0.07	0.04	0.00
11	0.24	0.00	0.03	0.07	0.00	0.00
12	0.24	0.00	0.00	0.06	0.00	0.00

According to IS-1893:2002 the number of modes to be used in the analysis should be such that the total sum of modal masses of all modes considered is at least 90 percent of the total seismic mass. Here the minimum modal mass is 95 percent.

Model-1 is having maximum time period of 1.18 s and model-2 is having maximum time period of 0.52 s. So, model-1 is more flexible than model-2.

Modal Analysis results show that there are some unusual modes (Fig. 6.1a) when diaphragm discontinuity modeled. However, the mass participation for those modes is found to be negligible. Therefore, these modes will not change the response of the building significantly.

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6.2 PUHOVER ANALYSIS RESULTS:

From the above graph we have seen that the push over curve of both the models are allmost coinsiding in X direction. In Y direction also the push over curve of both the models are almost coinsiding. Pushover Curves obtained from this study show that there is no significant difference in the response of the building for modelling discontinuous diaphragm.

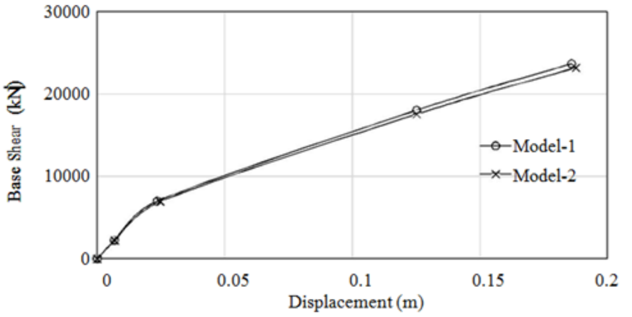

Fig. 6.2(a), Push curve – X

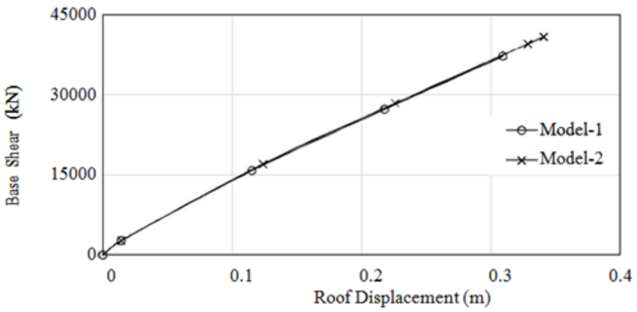

Fig. 6.2(b), Push curve – Y

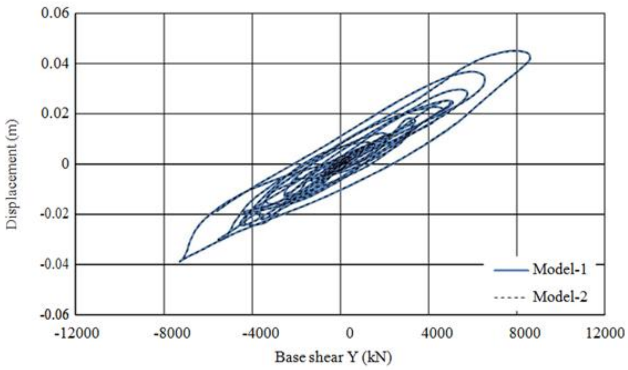

Fig 6.3 (c) Hysteresis curve of the building (Bi directional motion)

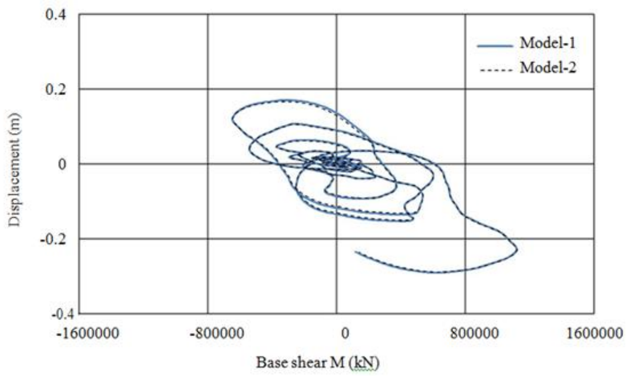

Fig 6.3 (d)Hysteresis curve of the building (Torsion)

In torsion also the hysteresis curve of both the models are coinsiding. Base shear vs. roof displacement hysteresis relation obtained from the non-linear time history analysis for both the models studied here are found to be identical.

6.4 CONCLUSION:

a) Discontinuous diaphragm makes the building flexible. Fundamental period of building with diaphragm discontinuity is found to be higher than a similar building with continuous diaphragm.

b) The empirical equation given in design codes (such as IS 1893:2002) are good for building with continuous diaphragm. The use of this equation for a building with discontinuous diaphragm can be very conservative.

c) Modal Analysis results show that there are some unusual modes when diaphragm discontinuity modelled. However, the mass participation for those modes are found to be negligible. Therefore, these modes will not change the response of the building significantly.

d) Pushover Curves obtained from this study show that there is no significant difference in the response of the building for modelling discontinuous diaphragm.

e) Base shear vs. roof displacement hysteresis relation obtained from the non-linear time history analysis for both the models studied here are found to be identical.

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f) This study indicates that modelling discontinuous diaphragm may not change the seismic behavior of framed building significantly.

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